Issued September 30, 1907.

United States Department of Agriculture,

OFFICE OF PUBLIC ROADS—Circular No. 88.

LOGAN WALLER PAGE, Director.

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No. 407. Progress of Road Legislation and Road Improvement in the Different States.

YEARBOOK OF THE DEPARTMENT OF AGRICULTURE, 1906.

No. 412. Object-lesson Roads.

LECTURE SYLLABUS.

Syllabus of illustrated lecture on roads and road building. Office of Experiment Stations, Farmers' Institute Lecture 7. By Office of Public Roads. 1907.

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* The Department's supply of this publication is exhausted.

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Issued August 28, 1908.

United States Department of Agriculture,

OFFICE OF PUBLIC ROADS—Circular No. 88, 2d revised edition.

LOGAN WALLER PAGE, Director.

PUBLICATIONS OF THE OFFICE OF PUBLIC ROADS.

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BULLETINS.

No. *1. State Laws Relating to the Management of Roads, enacted in 1888–1893. Compiled by Roy Stone. 1894.
*2. Proceedings of the Minnesota Good Roads Convention, held at St. Paul, Minn., Jan. 25, 26, 1894. 1894.
*3. Improvement of the Road System of Georgia. By O. H. Sheffield. 1894.
*4. Report on Road-making Materials in Arkansas. By J. C. Branner. 1894. Price, 5 cents.
*5. Information Regarding Road Materials and Transportation Rates in Certain States West of the Mississippi River. 1894. Price, 5 cents.
*6. Information Regarding Roads, Road Materials, and Freight Rates in Certain States North of the Ohio River. 1894. Price, 5 cents.
*7. Information Regarding Roads and Road-making Materials in Certain Eastern and Southern States. 1894.
*8. Earth Roads: Hints on Their Construction and Repair. By Roy Stone. 1894. Price, 5 cents.
*9. State Aid to Road Building in New Jersey. By Edward Burrough. 1894. Price, 5 cents.
*10. Proceedings of the National Road Conference, held at the Westminster Church, Asbury Park, N. J., July 5 and 6, 1894. 1894. Price, 5 cents.
*11. Proceedings of the Virginia Good Roads Convention, held in Richmond, Va., October 18, 1894. 1895.
12. Wide Tires. Laws of Certain States Relating to Their Use, and Other Pertinent Information. Compiled by Roy Stone. 1895. Price, 5 cents.
*13. Kentucky Highways. History of the Old and New Systems. By M. H. Crump. 1895.
*14. Good Roads. Extracts from Messages of Governors. Compiled by Roy Stone. 1895.
*15. Proceedings of the Good Roads Convention of Texas, held at Turner's Hall, in Houston, Tex., February 19, 1895. 1895. Price, 5 cents.

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No. *16. Notes on the Employment of Convicts in Connection with Road Building. Compiled by Roy Stone. 1895. Price, 5 cents.
*17. Historical and Technical Papers on Road Building in the United States. 1895. Price, 5 cents.
*18. State Laws Relating to the Management of Roads, enacted in 1894–95. Compiled by Roy Stone. 1895. Price, 5 cents.
Same. Supplement. 1895. Price, 5 cents.
*19. Progress of Road Construction in the United States: Reports by Delegates to National Road Parliament, held at Atlanta, Ga., October 17–19, 1895. 1897. Price, 5 cents.
*20. Traction Tests. By S. T. Neely. 1896. Price, 10 cents.
*21. Proceedings of the International Good Roads Congress, held at Buffalo, N. Y., September 16 to 21, 1901. 1901. Price, 5 cents.
*22. Proceedings of the Third Annual Good Roads Convention of the Boards of Supervisors of the State of New York, held at Albany, N. Y., January 28 and 29, 1902. 1902. Price, 10 cents.
*23. Road Conventions in the Southern States, and Object-lesson Roads Constructed Under the Supervision of the Office of Public Road Inquiries, with the Cooperation of the Southern Railway. 1902. Price, 15 cents.
24. Proceedings of the North Carolina Good Roads Convention, held at Raleigh, February 12 and 13, 1902. 1903. Price, 10 cents.
*25. Proceedings of the Jefferson Memorial and Interstate Good Roads Convention, held at Charlottesville, Va., April 2, 3, and 4, 1902. 1902. Price, 10 cents.
26. Proceedings of the National Good Roads Convention, held at St. Louis, Mo., April 27 to 29, 1903. 1903. Price, 5 cents.
27. The Construction of Sand-clay and Burnt-clay Roads. By W. L. Spoon. 1906. Price, 10 cents.
28. The Decomposition of the Feldspars. By A. S. Cushman and Prevost Hubbard. 1907. Price, 10 cents.
29. The Construction of Macadam Roads. By A. B. Fletcher. 1907. Price, 10 cents.
30. The Corrosion of Iron. By A. S. Cushman. 1907. Price, 10 cents.
31. Examination and Classification of Rocks for Road Building, Including the Physical Properties of Rocks with Reference to Their Mineral Composition and Structure. By E. C. E. Lord. 1907. Price, 15 cents.
32. Public-road Mileage, Revenues, and Expenditures in the United States in 1904. By M. O. Eldridge. 1907. Price, 15 cents.
33. Road Materials of Southern and Eastern Maine. By Henry Leighton and Edson S. Bastin. 1908. (In press.)
34. Dust Preventives. By Prevost Hubbard. 1908. (In press.)

CIRCULARS.[1]

No. *14. Addresses on Road Improvement. By Roy Stone. 1894.
*15. An Act to Provide for the Construction of Roads by Local Assessment, County, and State Aid, passed by the New York Assembly. 1894.
*16. Highway Taxation: Comparative Results of Labor and Money Systems. 1894.
*17. Origin and Work of the Darlington Road League. By Roy Stone. 1895.
18. Report of Committee on Legislation Adopted by the State Good Roads Convention, held in Richmond, Va., October 10 and 11, 1895. 1895.
*19. Traffic of the Country Roads. 1896.
*20. Comments on Systems of Maintaining Country Roads. 1896.
21. Methods of Constructing Macadamized Roads. 1896.
*22. Appeal for Organization of State and Local Road-improvement Societies. By C. A. Locke. 1896.
*23. Money Value of Good Roads to Farmers. By W. C. Latta. 1896.
24. Highway Maintenance and Repairs. Revision of Circulars 16, 20, and 24. 1897.
*25. Brick Paving for Country Roads. 1896.
*26. Going in Debt for Good Roads. 1897.
27. Cost of Hauling Farm Products to Market or to Shipping Points in European Countries. 1897.

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*The Department's supply of this publication is exhausted.
[1] Circulars 1–13 were of temporary character and are no longer in print.

No. *28. Addresses on Road Improvement in Maine, New York, North Carolina, and Illinois. By Roy Stone. 1897.

*29. The Forces Which Operate to Destroy Roads, with Notes on Road Stones and Problems Therewith Connected. By C. L. Whittle. 1897.

*30. Repairs on Macadam Roads. By E. G. Harrison. 1898.

*31. Must the Farmer Pay for Good Roads? By Otto Dorner.

32. State Aid to Road Building in Minnesota. By A. B. Choate. 1898.

*33. Road Improvement in Governors' Messages. 1899.

*34. The Social, Commercial, and Economic Phases of the Road Subject. By W. H. Moore. 1900.

*35. Road Improvement in New York. 1900.

*36. List of National, State, and Local Road Associations and Kindred Organizations in the United States. 1902.

37. The Railroads and the Wagon Roads. By A. L. Craig. 1904.

38. A Study of Rock Decomposition Under the Action of Water. By A. S. Cushman. 1905.

*39. Public Roads of the State of Washington: Mileage and Expenditures in 1904. By M. O. Eldridge. 1906.

40. Public Roads of Arizona: Mileage and Expenditures in 1904. By M. O. Eldridge. 1906.

41. Public Roads of Arkansas: Mileage and Expenditures in 1904. By M. O. Eldridge. 1906.

42. Public Roads of Oregon: Mileage and Expenditures in 1904. By M. O. Eldridge. 1906.

*43. Public Roads of Iowa: Mileage and Expenditures in 1904. By M. O. Eldridge. 1906.

*44. Public Roads of Virginia: Mileage and Expenditures in 1904. By M. O. Eldridge. 1906.

45. Public Roads of North Carolina: Mileage and Expenditures in 1904. By M. O. Eldridge. 1906.

*46. Public Roads of Alabama: Mileage and Expenditures in 1904. By M. O. Eldridge. 1906.

47. Tar and Oil for Road Improvement: Report of Progress of Experiments at Jackson, Tenn. 1906.

48. Public Roads of Tennessee: Mileage and Expenditures in 1904. By M. O. Eldridge. 1906.

49. Public Roads of New Hampshire: Mileage and Expenditures in 1904. By M. O. Eldridge. 1906.

50. Public Roads of Maryland: Mileage and Expenditures in 1904. By M. O. Eldridge. 1906.

51. Public Roads of Maine: Mileage and Expenditures in 1904. By M. O. Eldridge. 1906.

52. Public Roads of New Mexico: Mileage and Expenditures in 1904. By M. O. Eldridge. 1906.

53. Public Roads of Pennsylvania: Mileage and Expenditures in 1904. By M. O. Eldridge. 1906.

54. Public Roads of Montana: Mileage and Expenditures in 1904. By M. O. Eldridge. 1906.

55. Public Roads of Wyoming: Mileage and Expenditures in 1904. By M. O. Eldridge. 1906.

56. Public Roads of North Dakota: Mileage and Expenditures in 1904. By M. O. Eldridge. 1906.

57. Public Roads of South Dakota: Mileage and Expenditures in 1904. By M. O. Eldridge. 1906.

58. Public Roads of Kentucky: Mileage and Expenditures in 1904. By M. O. Eldridge. 1906.

59. Public Roads of Florida: Mileage and Expenditures in 1904. By M. O. Eldridge. 1906.

60. Public Roads of South Carolina: Mileage and Expenditures in 1904. By M. O. Eldridge. 1906.

61. Public Roads of Nebraska: Mileage and Expenditures in 1904. By M. O. Eldridge. 1906.

62. Public Roads of Nevada: Mileage and Expenditures in 1904. By M. O. Eldridge. 1906.

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No. 63. Public Roads of Kansas: Mileage and Expenditures in 1904. By M. O. Eldridge. 1906.
64. Public Roads of Idaho: Mileage and Expenditures in 1904. By M. O. Eldridge. 1906.
65. Public Roads of Colorado: Mileage and Expenditures in 1904. By M. O. Eldridge. 1906.
66. Public Roads of Indiana: Mileage and Expenditures in 1904. By M. O. Eldridge. 1907.
67. Public Roads of Oklahoma: Mileage and Expenditures in 1904. By M. O. Eldridge. 1907.
68. Public Roads of Utah: Mileage and Expenditures in 1904. By M. O. Eldridge. 1907.
69. Public Roads of California: Mileage and Expenditures in 1904. By M. O. Eldridge. 1907.
70. Public Roads of Illinois: Mileage and Expenditures in 1904. By M. O. Eldridge. 1907.
71. Public Roads of New Jersey: Mileage and Expenditures in 1904. By M. O. Eldridge. 1907.
72. Public Roads of Missouri: Mileage and Expenditures in 1904. By M. O. Eldridge. 1907.
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74. Public Roads of New York: Mileage and Expenditures in 1904. By M. O. Eldridge. 1907.
75. Public Roads of Ohio: Mileage and Expenditures in 1904. By M. O. Eldridge. 1907.
76. Public Roads of Georgia: Mileage and Expenditures in 1904. By M. O. Eldridge. 1907.
77. Public Roads of Mississippi: Mileage and Expenditures in 1904. By M. O. Eldridge. 1907.
78. Public Roads of West Virginia: Mileage and Expenditures in 1904. By M. O. Eldridge. 1907.
79. Public Roads of Wisconsin: Mileage and Expenditures in 1904. By M. O. Eldridge. 1907.
80. Public Roads of Minnesota: Mileage and Expenditures in 1904. By M. O. Eldridge. 1907.
81. Public Roads of Delaware: Mileage and Expenditures in 1904. By M. O. Eldridge. 1907.
82. Public Roads of Michigan: Mileage and Expenditures in 1904. By M. O. Eldridge. 1907.
83. Public Roads of Rhode Island: Mileage and Expenditures in 1904. By M. O. Eldridge. 1907.
84. Public Roads of Massachusetts: Mileage and Expenditures in 1904. By M. O. Eldridge. 1907.
85. Public Roads of Texas: Mileage and Expenditures in 1904. By M. O. Eldridge. 1907.
86. Public Roads of Connecticut: Mileage and Expenditures in 1904. By M. O. Eldridge. 1907.
87. Public Roads of Vermont: Mileage and Expenditures in 1904. By M. O. Eldridge. 1907.
88. Publications of the Office of Public Roads. Revised August, 1908.
89. Progress Reports of Experiments with Dust Preventives. 1908.

FARMERS' BULLETINS.

No. *95. Good Roads for Farmers. By M. O. Eldridge. 1900.
*136. Earth Roads. By M. O. Eldridge. 1902.
235. Cement Mortar and Concrete: Preparation and Use for Farm Purposes. By P. L. Wormeley, jr. 1905.
239. The Corrosion of Fence Wire. By A. S. Cushman. 1905.
311. Sand-clay and Burnt-clay Roads. By W. L. Spoon. 1907.
321. The Use of the Split-log Drag on Earth Roads. By D. W. King. 1908.
Macadam Roads. By A. B. Fletcher. 1908. (In press.)

*The Department's supply of this publication is exhausted.

YEARBOOK ARTICLES.

Articles on road construction which have appeared in Yearbooks of the Department have been reprinted in pamphlet form. Applicants for these should give both numbers and titles.

YEARBOOK OF THE DEPARTMENT OF AGRICULTURE, 1894.

No. *24. Best Roads for Farms and Farming Districts.
*25. State Highways in Massachusetts.
*26. Improvement of Public Roads in North Carolina.

YEARBOOK OF THE DEPARTMENT OF AGRICULTURE, 1895.

No. *40. Cooperative Road Construction.

YEARBOOK OF THE DEPARTMENT OF AGRICULTURE, 1897.

No. *118. Object-lesson Roads.

YEARBOOK OF THE DEPARTMENT OF AGRICULTURE, 1898.

No. 149. Steel-track Wagon Roads.
*150. Construction of Good Country Roads.

YEARBOOK OF THE DEPARTMENT OF AGRICULTURE, 1899.

No. *172. Progress of Road Building in the United States.

YEARBOOK OF THE DEPARTMENT OF AGRICULTURE, 1900.

No. 204. The Selection of Materials for Macadam Roads.
210. Mountain Roads.

YEARBOOK OF THE DEPARTMENT OF AGRICULTURE, 1901.

No. 240. Road Building with Convict Labor in the Southern States.
245. Government Cooperation in Object-lesson Road Work.
253. Mountain Roads as a Source of Revenue.

YEARBOOK OF THE DEPARTMENT OF AGRICULTURE, 1902.

No. 296. Use of Mineral Oil in Road Improvement.

YEARBOOK OF THE DEPARTMENT OF AGRICULTURE, 1903.

No. *305. Progress of Road Building in the Middle West.
332. Building Sand-clay Roads in Southern States.

YEARBOOK OF THE DEPARTMENT OF AGRICULTURE, 1904.

No. 350. Practical Road Building in Madison County, Tennessee.

YEARBOOK OF THE DEPARTMENT OF AGRICULTURE, 1905.

No. 407. Progress of Road Legislation and Road Improvement in the Different States.

YEARBOOK OF THE DEPARTMENT OF AGRICULTURE, 1906.

No. 412. Object-lesson Roads.

YEARBOOK OF THE DEPARTMENT OF AGRICULTURE, 1907.

LECTURE SYLLABUS.

No. 448. Dust Preventives.
Syllabus of illustrated lecture on roads and road building. Office of Experiment Stations, Farmers' Institute Lecture 7. By Office of Public Roads. 1907.

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* The Department's supply of this publication is exhausted.

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Issued April 20, 1908.

United States Department of Agriculture,

OFFICE OF PUBLIC ROADS—Circular No. 89.

LOGAN WALLER PAGE, Director.

PROGRESS REPORTS OF EXPERIMENTS WITH DUST PREVENTIVES.

INTRODUCTION.

The subject of dust prevention, owing to its direct relation to road preservation, is of vital importance to the road builder. During the past few years a number of preparations for laying and preventing dust on road surfaces have appeared on the market in competition with crude materials such as coal tar and petroleum, and it was therefore decided by the Office of Public Roads to carry on a series of experiments during the summer of 1907 with a view to determining, if possible, the relative value of these preparations and crude products and their adaptability to different conditions. The project embraced many details and, owing to lack of funds and the difficulty in finding one road suitable for all kinds of experiments, had to be somewhat modified in the final plans and the work divided among three localities. Since it is the intention of the Office, at a later date, to issue a bulletin which shall cover the entire subject of dust prevention in detail, only a brief description of the experiments made and the results so far obtained will be included in this report.

EXPERIMENTS AT WAYLAND, MASS.

CRUDE TAR AND TAR PREPARATIONS.

It was learned that the highway commission of Massachusetts intended to treat a stretch of road leading into Boston with a tar preparation, and arrangements were made by which the Office of Public Roads could carry on a number of experiments on sections of this road. According to agreement the necessary labor and apparatus were to be furnished by the commission, while the materials and supervision of their application were to be supplied by the Office.

The road selected for the experiments was a mixed trap and granite macadam in the townships of Weston and Wayland, which had been

built about ten years previously and had had but few repairs since that time. It is part of the main thoroughfare connecting New York with Boston and located about 16 miles from the center of the latter city.

The automobile traffic is for this reason heavy, and this, in addition to teaming and other traffic, had produced serious results. In some cases the macadam was completely broken through. There were many rut holes, some of them 30 feet long and averaging from 1 to 3 feet in width, and a large number of smaller holes more nearly circular in shape. Over almost the entire road surface numerous small depressions or worn places were visible and practically all of the fine material was being removed by traffic as fast as it was formed. The No. 1 or large-sized stones protruded above the surface, and in many cases were scattered loose, making the road extremely rough. Every rapidly moving automobile which passed would, in dry weather, raise a cloud of dust, which would be blown over the surrounding country, causing considerable annoyance to near-by dwellers as well as damage to the road.

It was thought that a road in this condition would give quicker comparative results than one in better shape to start with, and for this reason it was selected, although it was fully realized that the test would be a most severe one and the cost considerably above the average on account of preliminary repairs and the necessity for applying more of the dust preventive and a heavier surface dressing of gravel or screenings than are ordinarily required. Sections of this road as nearly alike as possible were selected for the experiments, which were made with water-gas tar, crude coal tar, various mixtures of the two applied in different ways, and a special coal-tar product.

The water-gas tar was obtained from a local gas company at $1.50 per barrel of 50 gallons, delivered. Most of it was sent in a large tank wagon and the remainder in barrels. It was a thin, oily liquid, having the properties shown in the following table. The crude coal tar was also obtained from a local gas company in 50-gallon barrels at $2 per barrel, delivered at Wayland. It had been produced at a comparatively low temperature and contained a good pitch base. The special coal-tar product was supplied free of charge by the manufacturing company in 50-gallon barrels, the Office paying freight on it from Boston to Wayland. It contained no water, was free from the extremely volatile oils present in the crude tar, and held a good pitch base. Its other properties are shown in comparison with the water-gas and coal tars in the following table. The composition of these materials is given in percentage volumes, and the remarks refer to the condition of distillates and residues when cold.

TABLE 1.—*Specific gravity and composition of tar products.*

Kind of tar.	Specific gravity.	Ammoniacal water.	Total light oils to 170° C.	Total dead oils, 170°–270° C.	Residue, per cent by difference.
Water-gas tar	1.041	2.4	[a] 21.6	[b] 52.0	[c] 24.0
Coal tar	1.210	2.0	[d] 17.2	[e] 26.0	[f] 54.8
Special tar preparation	1.177	0.0	[b] 12.8	[g] 47.6	[f] 39.6

[a] Distillate mostly liquid.
[b] Distillate all liquid.
[c] Pitch very brittle.
[d] Distillate mostly solid.
[e] Distillate one-half solid.
[f] Pitch hard and brittle.
[g] Distillate one-third solid.

Labor was furnished to the highway commission under contract, the contractor receiving a stated per diem salary and a bonus of 15 per cent of the actual cost of the labor supplied. This cost per eight-hour day was as follows:

Common labor	\$1.50–\$1.85
Single teams	3.00
Double teams	5.00
Foreman	3.00
Steam roller	12.00

Two steam rollers were employed, and as one belonged to the highway commission, the cost per diem of running it included only the hire of the engineer at \$2.50 per day and cost of fuel. A 12-barrel heating kettle with a portable fire box and mounted on wheels, stiff street-sweeping brooms, picks, shovels, etc., a 2-horse sweeper, and a tank wagon for the water-gas tar, constituted the outfit necessary to carry on the work.

As the road was in bad condition, it was found necessary to make extensive repairs before applying the tar. The places to be repaired were first loosened with hand picks and the No. 1 stone separated from the finer material and returned to the holes, after which enough No. 2 stone was spread to give as nearly as possible an even surface to the road when rolled. There were, however, numerous small depressions or worn places which were too shallow to patch successfully, but deep enough to give the road an uneven appearance when completed. In one section it was found necessary to resurface the road completely. All extra material needed for repairs was taken from piles which had been previously distributed along the road by the highway commission, but in estimating costs, the value of the crushed rock in place was allowed for. The cost of repairs per square yard of road surface was from 2.6 to 3.3 cents.

The tar was applied during the month of August and only in dry, warm weather. The method in general was as follows, although some exceptions were made which will be noted under the descriptions of the different experiments. All loose materials, dust, and detritus were first removed by repeated trips of the sweeper, just be-

fore the application of the tar. Hot or cold tar, according to the experiment, was then spread upon the clean, dry road through a hose connected to the kettle or tank wagon, as the case might be. Laborers followed the kettle, spreading and working the tar into the road surface with stiff, long-handled brooms. As the road could not be closed to traffic, it was found necessary to throw on a light covering of gravel or screenings almost immediately, in order to prevent passing automobiles from picking up the tar, although it would have been much more satisfactory and productive of better results could the tar have been allowed to dry for a number of hours before applying the surface dressing. Finally, enough of the covering material was added to take up the excess tar and produce an even surface, and the whole well rolled with a 12-ton steam roller until firm and smooth. When gravel was used it was obtained from pits located near the road and cost the highway commission about $1.08 per cubic yard, during the time covered by the work of the Office. One-half inch clean trap screenings or pea stone, however, was used whenever it could be obtained and was furnished at $1.10 per ton by a rock-crushing plant located about 4 miles from the nearest section of the work.

Before the road was entirely completed it was found necessary to remove the dust and waste material which had accumulated and been swept into the gutters. This had to be carted away and dumped in convenient places near the road. It added from 1 to 1.3 cents per square yard to the total cost of treatment. In estimating the cost per square yard of the different sections, these figures are included in proportion to the length of section treated. Work of a general nature, such as unloading, hauling, etc., is also divided proportionately among the different sections in computing the cost.

Thirteen different experiments were made, four with water-gas tar alone, three with coal tar, three with mixtures of water-gas tar and coal tar, and three with special tar preparations. The following is a brief description of each, with a statement of cost and the results obtained after three months.

Experiment No. 1.—Water-Gas Tar.

A section of road having numerous ruts and holes was first thoroughly swept and repairs made where required. It was found necessary to have the sweeping done first, in order to prevent the sweeper from tearing up the loose stones in the patches. The unheated water-gas tar was then spread upon the road from the tank wagon and well broomed in. It was readily absorbed by the road surface and failed to hold a light coat of gravel which was spread and rolled down. Another application of tar was then made, and sufficient gravel added to absorb the excess tar completely. The surface was then well rolled,

but refused to compact properly and showed a strong tendency to pick up under the roller where the road was patched. Indications pointed strongly toward a failure, but after the road was subjected to traffic for a few days it was noticed that its appearance was somewhat improved, although the patches showed signs of raveling. In damp weather the road showed up to advantage and no disagreeable mud was noticed, even after heavy rains. In dry weather the dust was well laid and, although the top was not firmly compacted, it seemed to remain in place under the action of traffic. When inspected three months later, the road was in a much better condition. The loose surface had packed down well and the patches were holding much better than was to be expected from earlier observations. The road at that time was practically free from dust and presented a fairly good appearance.

The section thus treated was 1,275 feet in length. The tar was applied for a width of 12 feet, and with an average of 0.9 gallon of tar per square yard. If the road had contained fewer holes and been less in need of a heavy top dressing, a much smaller quantity of tar could undoubtedly have been made to give the same results. The cost of application was 4.9 cents for labor, 2.7 cents for tar, and 0.8 cent for gravel per square yard, and this, added to the cost of repairs, 3.2 cents, and of removing refuse material, 1.3 cents, makes a total of 12.9 cents per square yard. The entire area covered was 1,700 square yards. Thirteen and one-third cubic yards of gravel were applied and 15 cubic yards of refuse material removed.

Experiment No. 2.—Water-Gas Tar.

The section of road treated in this experiment was in about the same condition as the preceding one. The cost of repairs was about the same per square yard, but there were not so many large holes to be patched. The tar and gravel were applied in the same manner to the road, which had been well swept and repaired, but in this case only one treatment of each was given. The surface was well rolled, but as in the preceding case, it did not compact well, although no tendency to pick up under the roller was observed. The surface improved under traffic and held well in rainy weather. No dust was formed and, after one week, but little difference could be detected between the two sections. The color of this section, however, was somewhat lighter than No. 1. At the end of three months it compared very favorably with No. 1, although the surface was not quite so well compacted. It was practically dustless. This section was 125 feet in length, and application was made over a width of 12 feet. There was used on each square yard treated 0.38 gallon of tar. The cost of application was 4.9 cents per square yard for labor, 1.1 cents for tar, and 0.8 cent for gravel. Repairs cost 3.3 cents, and removing

waste material 1.3 cents, which gives a total of 11.4 cents per square yard. One hundred and sixty-seven square yards were treated, 1⅓ cubic yards of gravel applied, and 1½ cubic yards of waste material removed.

EXPERIMENT NO. 3.—WATER-GAS TAR.

For the purpose of determining the value of water-gas tar as a dust layer, without reference to its value as a surface binder, a section of road which was in excellent condition was sprinkled with this material. An ordinary sprinkling cart was used, and no attempt was made to clean the road surface before treatment. As much tar was applied as the road would absorb without becoming too muddy. No dressing of screenings or gravel was applied. When dry, the road showed a much darker color, the dust was well laid, and no formation of dust was noticed for two weeks after treatment. At the end of three months very little dust was raised by a rapidly moving automobile, and the road surface seemed to be considerably hardened by the residual matter retained after the more volatile products of the tar had evaporated.

A length of 300 feet of roadway was treated in this manner for a width of 15 feet, and 0.3 gallon of tar applied per square yard. For the short section treated, the cost of labor amounted to 0.6 cent per square yard, and the material 0.9 cent, making a total of 1.5 cents per square yard. For long stretches of road, however, the cost could undoubtedly be cut down to slightly over 1 cent per square yard.

EXPERIMENT NO. 4.—WATER-GAS TAR.

For this experiment a short section of road in good condition was selected, in order to make a direct comparison with No. 3. In this case the road was first carefully swept and the tar allowed to run upon it from barrels and thoroughly broomed in. A sprinkler would have served the purpose equally well, but the section was so short that it was not considered worth while to apply the tar in that way. In this case the road would absorb only 0.25 gallon of tar per square yard. It presented much the same appearance as in experiment No. 3, but owing to the removal of all of the dust and fine material it was rougher and therefore less satisfactory. No dust formed, even at the end of three months, but the road at that time lacked the thin cushion of fine material that was held by No. 3. From these two experiments it is evident that the presence of dust and other fine material on the road is rather beneficial than otherwise when water-gas tar is applied.

A section of roadway 150 feet long and 12 feet wide was treated in this way. The cost of application amounted to 1.3 cents per square yard for labor and 0.8 cent for material, while the cost of removing

waste material from the gutters was 1.2 cents, making a total of 3.3 cents per square yard. An area of 200 square yards was treated, and 1.8 cubic yards of waste material removed.

Experiment No. 5.—Coal Tar.

The section selected for this experiment was in about the same condition as that for experiment No. 1. Large ruts and holes were numerous and had to be patched after the road had been carefully swept. The coal tar was first heated to a temperature of 180° F. in the kettle, and then run upon the road from a hose connected to a draw-off at one end. A team of horses was necessary to move the kettle along the road in advance of the laborers, who spread and worked the hot tar with brooms into the road surface as fast as it was run from the kettle. Four men were required to do the brooming, while the foreman attended to running the tar from the kettle and supervised the work. Cords attached to stakes driven along the sides of the road were first used to measure the width to be tarred, but, after the laborers gained some experience, it was found unnecessary to do this, as they were then able to keep a fairly even line by eye. A coat of gravel was spread over the road soon after the tar had been applied and rolled down to a smooth, even surface during the same day. The large patches showed a tendency to wave and pick up under the roller, but the rest of the surface was well consolidated. After one week's service but little dust was raised by passing automobiles and at the end of three months the road was dustless and presented much the same appearance as asphalt, although the large patches were a little rough. The road seemed to shed water well and dried quickly after a rain.

The section thus treated was 150 feet in length, 15 feet wide, and 0.6 gallon of tar was applied per square yard. The cost of application was 6.1 cents per square yard for labor, 2.4 cents for tar, 0.8 cent for gravel, 2.6 cents for repairs, and 1 cent for removing waste material, which gives a total of 12.9 cents per square yard. An area of 250 square yards was treated, 2 cubic yards of gravel applied, and $2\frac{1}{4}$ cubic yards of waste material removed.

Experiment No. 6.—Coal Tar.

This experiment was made in the same manner and on a section of road similar in every respect to No. 5. A small quantity of the cold tar was first tried, but was not absorbed by the road, and could not be broomed to any advantage. It was found necessary to heat the tar to a temperature of 145° F. before it could be used satisfactorily, but when applied at this temperature gave results in every way as good as No. 5, although slightly more tar was required per square

yard than in that experiment. In this case, as in No. 5, the patches were not entirely satisfactory. A somewhat longer stretch of road was treated in this experiment and, although slightly more tar was used, the cost of application per square yard remained the same, as the labor item was lowered. The section treated was 600 feet in length and 15 feet in width, and 0.7 gallon was applied per square yard. For this application labor cost 5.6 cents, tar 2.8 cents, gravel 0.9 cent, while repairs cost 2.6 cents, and removing waste material 1 cent, making a total of 12.9 cents per square yard. An area of 1,000 square yards was treated, 8 cubic yards of gravel applied, and 9 cubic yards of waste material removed.

Experiment No. 7.—Coal Tar.

In order to get the best results possible with coal tar a section of road free from holes was selected. The road had been badly worn and the surface was somewhat rough, but was in good enough condition to provide a fair test. No preliminary repairs were made, but the road was well swept, as in the case of the other two experiments with coal tar, and the tar applied and broomed in in the same way at a temperature of 195° F. A heavy coat of gravel was then applied and well rolled and compacted, in order to produce a smooth surface when completed. For some time afterwards the road was slightly dusty, but at the end of three months it presented a better appearance than the other two sections, although not quite so much like asphalt. At that time it was practically dustless.

This section was 450 feet in length and was covered for a width of 12 feet. Only 0.42 gallon of tar was applied per square yard. The cost of application was 4.4 cents per square yard for labor, tar 1.7 cents, gravel 1.4 cents, and removing waste material 1.3 cents, which makes a total of 8.8 cents per square yard. An area of 600 square yards was treated, 8 cubic yards of gravel applied, and 5⅜ cubic yards of waste material removed.

Experiment No. 8.—Water-Gas Tar and Coal Tar.

A section of road containing many ruts and holes had been treated with water-gas tar in the same manner as No. 2, in which section it was first intended to be included. As gravel could not be applied the same day, however, and as the surface on the next day was too dry to hold down a top dressing, it was decided to finish the work by applying coal tar before spreading the gravel. The coal tar was applied in the same manner as in experiment No. 5, as was also a top coating of gravel which was afterwards well rolled. This section was inspected three months afterwards and it is very doubtful if the presence of the water-gas tar was of any advantage.

The section treated was 250 feet long and 15 feet wide, and 0.3 gallon of water-gas tar and 0.6 gallon of coal tar applied per square yard. The cost of application was 5.8 cents per square yard for labor, tar 3.3 cents, gravel 1 cent, 2.6 cents for repairs, and 1 cent for removing waste material, making a total of 13.7 cents per square yard. An area of 417 square yards was treated, 4 cubic yards of gravel applied, and 3¾ cubic yards of waste material removed.

EXPERIMENT NO. 9.—WATER-GAS TAR AND COAL TAR.

Since it was found that coal tar could not be applied satisfactorily when cold, it was thought that a mixture of coal tar and water-gas tar might be made which could be used without the trouble and expense of heating, and which at the same time would hold down a surface dressing better than water-gas tar alone, because of its greater body. A section of road, rough but free from holes, was selected for this experiment, and, after having been carefully swept, was treated with a mixture of equal parts water-gas tar and coal tar. This material was applied cold from the kettle in which it was made and a light covering of clean ½-inch trap screenings or pea stone spread on top. The mixture was not heavy enough to hold down as much dressing as should have been applied to bring the surface to a perfectly smooth condition, but when the road was well rolled a surface was formed which was fairly smooth and offered a good foothold for horses without increasing the resistance to traction of vehicles. The road was absolutely dustless when inspected three months later, and had worn somewhat smoother.

A section of roadway 560 feet long and 15 feet wide was treated with this mixture and 0.43 gallon applied per square yard. The cost of application for labor was 3 cents per square yard, tar 1.5 cents, screenings 0.7 cent, and for removing waste material 1 cent, making a total of 6.2 cents per square yard. An area of 933 square yards was treated, 8 cubic yards pea stone applied, and 8⅝ cubic yards of waste material removed from the gutters.

EXPERIMENT NO. 10.—WATER-GAS TAR AND COAL TAR.

A slightly heavier mixture was applied in this experiment on the same kind of road and in the same manner as in experiment No. 9, with the exception that gravel was used instead of pea stone for a top dressing. Five parts of coal tar was used to three parts of water-gas tar, and 0.48 gallon was applied per square yard. The mixture, however, did not hold down the gravel well. As a result, the road was slightly dusty for some time and, although in better condition at the end of three months, did not present as good an appearance as No. 9, and the surface seemed to be rather porous.

A section of road 1,000 feet long and 15 feet wide was treated in this manner and the cost of application was 3.7 cents for labor, tar 1.7 cents, surface material 0.8 cent, and 1 cent for removing waste material, making a total of 7.2 cents per square yard. The area covered was 1,667 square yards, 12 cubic yards of gravel was applied, and 15 cubic yards of waste material removed.

Experiment No. 11.—Special Tar Mixture.

A section of road, rough but free from holes, including a rather sharp curve, was selected for this experiment and, after being thoroughly swept, was treated with a mixture of water-gas tar, coal tar, rosin, and other substances applied at a temperature of 200° F. from a kettle in the same manner as in experiment No. 5. A rather heavy dressing of pea stone was then applied and rolled once or twice. A good asphalt-like surface was formed which was free from dust and which, at the end of three months, made a very favorable appearance in comparison with the other experiments. The surface was hard and resilient without offering the resistance to traction noticed on many of the other sections.

Two hundred feet of road 12 feet wide was treated and 0.42 gallon applied per square yard. The cost of application was 4.6 cents for labor, tar mixture 2.6 cents, pea stone 1.7 cents, and for removal of waste material 1.3 cents, making a total of 10.2 cents per square yard. An area of 267 square yards was treated, 5½ cubic yards of pea stone used, and 2⅗ cubic yards of waste material removed.

Experiment No. 12.—Special Tar Preparation.

A short section of road in such bad shape that resurfacing was necessary was selected for this experiment. The road was therefore first torn up with a steam roller fitted with spikes. A course of No. 2 stone was then spread on and rolled and followed by a course of pea stone, which was also thoroughly rolled. As the kettle could not be dragged across this road without tearing it up, the material, at a temperature of 218° F., was applied by means of coal hods and no attempt was made to broom it in. A large amount of the tar preparation was absorbed by the road and only a light course of pea stone was placed on top. The whole was then rolled for a short time and well consolidated. The road thus formed presented a fine appearance and was absolutely dustless. At the end of three months the appearance was still good, but a few rough and porous places existed, where the tar had gone through the surface and into the foundation. It was absolutely dustless, however. The treatment proved to be expensive and, unless very much better results follow than in the other experiments, it will prove too costly for general use.

A portion of road 75 feet long and 12 feet wide was treated in this manner and 1.5 gallons of the tar preparation applied per square yard. The cost of application was 14.8 cents for labor, 9 cents for material (reckoned at 6 cents per gallon), 3.3 cents for screenings, 3.3 cents for repairs (not including the pea stone), and 1.2 cents for removing waste material, which gives a total of 31.6 cents per square yard. One hundred square yards was covered, 4 cubic yards of pea stone used, and nine-tenths of a cubic yard of waste material removed from the gutters.

Experiment No. 13.—Special Tar Preparation.

A section of road free from holes but somewhat rough was selected for this experiment. Material similar to that used in experiment No. 12 was heated to 185° F. and applied to the road in the same manner as in experiment No. 5. The road had first been swept. A heavy covering of pea stone was then applied and rolled down. The surface formed was smooth and dustless, asphalt-like in appearance, and apparently waterproof. In very hot weather it was somewhat sticky in places, but this was doubtless due to the fact that more tar was used than was absolutely necessary. After three months it presented a smooth and even appearance and was dustless.

A section of road 490 feet long and 15 feet wide was treated in this experiment, and 0.67 gallon of the mixture was applied per square yard. The cost of application amounted to 5.8 cents for labor, 4 cents for tar mixture, 1.9 cents for pea stone, and 1 cent for removing waste material, giving a total of 12.7 cents per square yard. A total area of 817 square yards was treated, 18½ cubic yards of pea stone applied, and 7⅗ cubic yards of waste material removed.

SUMMARY OF EXPERIMENTS WITH TAR PRODUCTS.

In considering the tar experiments it will be noticed that in almost every case the cost for labor per square yard is high. This was largely due to the shortness of the sections treated, which made it impossible to handle large quantities of material at one time and prevented systematic routine work on the part of the laborers. Added to this, the cost of extensive repairs and of removing large quantities of waste material which had collected in the gutters, the total cost per square yard is in most cases considerably in excess of what similar work could be done for under ordinary conditions. The following table gives in condensed form the various items of labor and material relating to the different experiments.

TABLE 2.—*Cost data of tar experiments.*

Experiment No.	Material applied.	Cost of repairs per square yard.		Cost of application per square yard.			Cost of removing waste material per square yard.	Total cost per square yard.	Total cost of entire area.
		Labor.	Material.	Labor.	Material.	Surfacing.			
1	Water-gas tar	$0.022	$0.010	$0.049	$0.027	$0.008	$0.013	$0.129	$220.74
2	.....do	.023	.010	.049	.011	.008	.013	.114	19.03
3	.....do			.006	.009			.015	7.30
4	.....do			.013	.008		.012	.033	6.60
5	Coal tar	.018	.008	.061	.024	.008	.010	.129	32.46
6	.....do	.018	.008	.056	.028	.009	.010	.129	129.14
7	.....do			.044	.017	.014	.013	.088	52.82
8	Water-gas and coal tars	.018	.008	.058	.033	.010	.010	.137	57.49
9	.....do			.030	.015	.007	.010	.062	58.26
10	.....do			.037	.017	.008	.010	.072	119.89
11	Special tar mixture			.046	.026	.017	.013	.102	27.27
12	Special tar preparation	.023	.010	.148	.090	.033	.012	.316	31.64
13	.....do			.058	.040	.019	.010	.127	103.45
	Total	72.28	36.00	382.07	203.38	82.26	90.10	....	866.09

TABLE 3.—*Miscellaneous data of tar experiments.*

Experiment No.	Material applied.	Surface application.	Number of gallons of material applied per square yard.	Surfacing material, cubic yards per square yard.	Waste material removed, cubic yards per square yard.	Area covered, square yards.
1	Water-gas tar	Gravel	0.90	0.0079	0.009	1,700
2	.....do	.....do	.38	.0080	.009	167
3	.....do	None	.30			500
4	.....do	.....do	.25		.009	200
5	Coal tar	Gravel	.60	.0080	.009	250
6	.....do	.....do	.70	.0080	.009	1,000
7	.....do	.....do	.42	.0133	.009	600
8	Water-gas and coal tars	.....do	.90	.0096	.009	417
9	.....do	Pea stone	.43	.0086	.009	933
10	.....do	Gravel	.48	.0072	.009	1,667
11	Special tar mixture	Pea stone	.42	.0202	.009	267
12	Special tar preparation	.....do	1.50	.0400	.009	100
13	.....do	.....do	.67	.0226	.009	817
	Total					11,118

Nearly all of the sections were in good condition when they were inspected in November. It is impossible at the present time to make decided comparisons of the values of the different surfacings, but, undoubtedly, after the cold rains and frosts of winter, conclusions may be reached as to the worth of each one, for these agencies are the worst enemies of work of this kind. Some facts of interest have already been noted which it may be well to mention at this point. It has been shown that water-gas tar is a satisfactory dust layer and preventive when used in moderate quantities on roads already in fairly good condition. It can undoubtedly be applied to the best advantage by means of an ordinary sprinkling cart on the unprepared road, and when used in this way serves to make the road sur-

face firm and keep down the dust for some time at a very reasonable cost. Its odor is objectionable at first, but soon disappears. It must necessarily be applied more frequently than the heavier tars, owing to its lack of body. Where extensive repairs have to be made before treatment it has but little value as a binder for the large, loose material, and whether its use even in large quantities will be satisfactory for this purpose and for holding down a heavy surface dressing is a matter for the future to decide.

At the present time some of the experiments with crude coal tar show up favorably in comparison with the work with special preparations, but time is needed to decide definitely upon their relative merits. As regards application, the special preparation has the advantage over crude coal tar in being less inflammable and less likely to boil over the sides of the kettle if heated too high, but, on the other hand, its cost is considerably greater. Two criticisms, which have already been offered by farmers to both of these products, are that the traction of heavily loaded wagons is increased and that in frosty weather the road is made very slippery and offers but little foothold to horses. While the mixtures of water-gas tar and coal tar, with a light dressing of trap screenings, give better results in these respects, it is impossible at the present time to say that their use will prove as satisfactory or economical in the long run. A material which can be applied cold is much easier to handle than one requiring heat, but of course the latter has the advantage of containing more binding material or base. Where surface dressing is needed the use of clean ½-inch screenings is certainly to be preferred to gravel, as less rolling is required and a better wearing surface is produced.

The surface treatment of roads with tar is more a palliative than a preventive of the dust nuisance. Some more permanent treatment of the road is essential for lasting results. It is the intention of the Office in the near future to carry on experiments along the latter line, with the use of a well-tarred sand to supply a part of the binding material and to fill the voids. One of the most promising methods with respect to cost which has suggested itself is to apply a layer of this tarred sand to the bottom course of No. 1 stones, which should first be well rolled. The second course of No. 2 stones should then be applied and the whole rolled until the sand has been thoroughly worked into both the upper and lower courses. A surface application of tar should then be put on and sufficient sand or fine stone chips spread to bring the surface to a smooth and uniform condition when rolled.

EXPERIMENTS WITH OIL EMULSIONS.

It was the intention of the Office at first to experiment upon this same road with calcium chloride and a number of oil emulsions, but,

as there proved to be no convenient water supply at hand, it was found impossible to give these preparations a fair trial. As a quantity of material had, however, been donated for this purpose, it was used to the best advantage under existing conditions and in spite of many drawbacks gave fairly satisfactory results and indications of what might have been accomplished under more favorable circumstances. The materials used were specially prepared residual Texas oil emulsions. Both were capable of being mixed with water in all proportions. Upon examination, emulsion No. 1 was found to contain an asphalt-like base of 30 per cent and emulsion No. 2 a similar base of 57.5 per cent. They were mixed with water and applied from a sprinkling wagon upon sections of unswept road in fairly good condition.

Two applications of emulsion No. 1 were made twenty days apart. A 25 per cent mixture was used, the sprinkling cart traveling three times over the road during each application, once down each side and once over the middle. As the sprinkler covered about two-thirds of the width of the road, the center received about three times as much material as the sides. The preparation was well absorbed by the road, which assumed a somewhat darker color, and but little dust was noticed even at the end of three months. A thin coating of asphaltic base was retained by the road surface, which hardened upon drying, and undoubtedly tended to reduce the wear of traffic.

A section 700 feet long and 15 feet wide was treated in this manner, 0.19 gallon of the oil emulsion or 0.76 gallon of the solution being applied per square yard. Reckoned at 16 cents per gallon, the cost of application was 3.2 cents per square yard for material and 0.6 cent for labor, making a total of 3.8 cents per square yard.

Emulsion No. 2 was applied in the same manner as emulsion No. 1, but in this case only one application of a 23 per cent solution was made. The road thus treated had a somewhat darker appearance than that treated with the first emulsion. The general effects were similar and as the material sells at the same price as emulsion No. 1 its use proved more economical. It was, however, a little more difficult to handle and not as readily miscible with water.

A section 800 feet long and 15 feet wide was treated with this product and about 0.1 gallon of emulsion No. 2 or 0.4 gallon of solution was applied per square yard. The cost of application was 0.2 cent for labor and 1.5 cents for material, making a total of 1.7 cents per square yard.

The results obtained from the use of these materials may be compared with those from using water-gas tar, when light applications of the latter are made by sprinkling. Emulsion No. 2 has but little odor, while emulsion No. 1 has a rather strong though not exceed-

ingly disagreeable odor, which, like that of water-gas tar, soon disappears. While the application of water-gas tar has the advantage of not being dependent upon a water supply, this special preparation, on the other hand, can be transported at a much lower rate, owing to its concentrated state.

EXPERIMENTS AT WASHINGTON, D. C.

CALCIUM CHLORIDE.

The value of calcium chloride as a dust preventive was tested on the portion of the macadam driveway in the Agricultural Department grounds, in Washington, D. C., which connects Twelfth and Fourteenth streets.

The roadway is built of trap rock, held in position by a soft limestone binder. The screenings of this binder pulverized rapidly under traffic, forming a light dust which passing vehicles continually raised into the air. It was then carried away by the wind. In this way the road was becoming stripped of its binding material.

In preparation for the treatment all dust and dirt was scraped from the surface of the roadway. A solution was prepared by mixing 300 pounds of commercial calcium chloride (granular, containing 75 per cent calcium chloride and 25 per cent moisture) with 300 gallons of water in an ordinary street sprinkler, care being taken to agitate the liquid thoroughly before applying it to insure a uniform solution. It was then applied from one sprinkling head, and the sprinkler passed slowly back and forth over the road to facilitate the complete absorption of the solution. Each application consisted of 600 gallons over an area of 1,582 square yards, or 0.38 gallon per square yard.

The first application was made July 13, 1907, followed by a similar one July 15, to increase the efficacy of the treatment. The effect of the first two treatments was marked. No auxiliary sprinkling was necessary for some time, the light rains falling at intervals supplying all the moisture required. The untreated portions of the driveway lying parallel to Twelfth and Fourteenth streets were sprinkled daily and vehicles raised a perceptible dust, although the traffic over these wings was much less heavy than that on the treated portions.

During this time the appearance of the roadway varied perceptibly in color according to the moisture in the road surface, ranging from a light gray when dry to a peculiar grayish brown when moist. The brown shades were deepest over the portions traversed by the wheels of vehicles. The texture of the road surface was completely changed after the application of the calcium chloride. Before treatment, raveling was excessive in spots and the whole surface seemed loosely knit together. After the application on July 15 this condition changed and the road surface became smooth, compact, and resilient.

The third treatment was given August 3, as certain points exposed to the most severe wear were showing signs of raveling. The phenomena following this treatment were not unlike those attending the first set of applications and repeated themselves as later applications were made, though no further treatments were given until the condition of the roadway seemed to demand it. Such auxiliary sprinkling as was necessary consisted in the application of about 0.2 gallon of water per square yard at a time.

Table 3 shows cost of applications. The calcium chloride was donated by a manufacturing chemical company of Baltimore, Md., and is charged at the rate of $16 per ton, f. o. b. cars at Baltimore. A freight charge of 13 cents per hundredweight is added to place the material on the ground.

TABLE 4.—*Cost of applying calcium chloride.*

Item.	Cost.
600 pounds calcium chloride, at $18.60 per ton	$5.58
3 men for 1½ hours, at 15 cents per hour	.675
1-horse sprinkling wagon for 1½ hours, at 35 cents per hour	.525
Total cost of 1,582 square yards	6.78
Cost per square yard at this rate	.0043
Total cost of five applications	33.90
Cost per square yard of five applications	.0235

The specific gravity of these solutions ranged from 1.053 to 1.060. Some variation was unavoidable, as the calcium chloride in some of the barrels had absorbed a large amount of moisture from the atmosphere. In such cases the actual percentage of the chemical to 300 pounds was less than where little or no moisture had been absorbed.

At the time of the last application several hundred pounds of the salt remained unused. This was divided as nearly as possible into two parts, to be applied to the two wings of the driveway lying parallel to Twelfth and Fourteenth streets. The east wing received a treatment of 0.28 gallon per square yard of a solution the specific gravity of which was 1.145 and the west wing a similar application of a solution having a specific gravity of 1.121. No further sprinkling was found necessary for the remainder of the season upon these branches of the main driveway.

EXPERIMENTS AT BOWLING GREEN, KY.

ROCK ASPHALT, CRUDE OIL, AND A SPECIAL OIL PREPARATION.

Another series of experiments was conducted by this Office at Bowling Green, Ky. The materials used were Kentucky rock asphalt tested for its fitness as a binder in macadam construction, crude Kentucky oil, and a special preparation of residuum oils, the last two of which were used as dust preventives. This work was done in coop-

eration with the authorities of Warren County and lay just beyond the city limits of Bowling Green. The location of each section of experimental work is given in connection with its description.

ROCK ASPHALT EXPERIMENT.

The rock asphalt used in this experiment is a natural product formed in the Chester group of subcarboniferous rocks over a course extending through Breckinridge, Grayson, Edmonson, Logan, and Warren counties in Kentucky, marking the edge of the coal fields lying in the western part of that State. It is a fine-grained sandstone which in the past has been impregnated with mineral pitch or bitumen, the latter averaging from 6 to 8 per cent, with a maximum of 12 per cent. Both appearance and impregnation are irregular, for it is generally found in pockets rather than in distinct continuous veins, and the distribution of the bitumen over the pocket ranges from a mere trace to saturation.

The quarrying and first crushing of rock asphalt are not unlike that of other rock intended for macadam or concrete work. After having been broken into pieces to pass through a 2-inch ring, it is conducted to a series of roll crushers, consisting of parallel steel cylinders. The bitumen in the rock gives sufficient adhesion to carry the material through the rolls, once it has been forced against them. The finished product after crushing is a mass of individual grains of sand, each thoroughly coated with a film of mineral pitch sufficiently glutinous to cause it to adhere to surrounding grains and to pack very firmly if subjected to pressure. If chilled when compacted, a lump becomes very hard and tough; if warmed in the hand, the bitumen becomes soft and semifluid and the individual grains of sand fall from the mass of their own weight. When freshly crushed it is of rich dark brown color with a slight luster which gradually disappears as the bitumen hardens and dries.

The test was made on what is known as Cemetery pike, running east from the city limits of Bowling Green. It is the main thoroughfare leading from the southern and eastern parts of Warren County to Bowling Green, the county seat, and, besides being the route for heavy rural traffic, it passes extensive gravel beds and timber lands from which heavy loads are being constantly taken on narrow tires. The form of construction originally adopted was a 20-foot Telford road. When this surface had been worn away under traffic and the foundation exposed it was repaired and brought to grade with a sharp gravel containing about 20 per cent of sand and clay. This bed of gravel was about 8 inches thick, compacted. Previously to the experiments it was loosened to a depth of 4 inches by means of a spiked roller and a heavy harrow and was shoveled out by hand.

The subgrade was then made to conform to the crown of the roadway, which was planned to be 4½ inches in 9 feet, or an average of one-half inch per foot. The gravel removed in shaping the subgrade was used for repairs on the roadway beyond the work.

After thoroughly compacting the subgrade with a roller the wearing course of stone was laid. It consisted of limestone crushed to range from 1 inch to 1½ inches in largest dimension and was spread to a uniform depth of 4 inches. This course was then rolled once to turn down the sharp edges of the stone and form a smooth, even surface. No further attempt was made to reduce the voids in the stone by compacting it, as these were to be filled with the rock asphalt. This material was then thrown on with shovels from wagons and dumping boards along one side of the road. It was spread to a depth of 1½ inches, care being taken to break all lumps and to work all the asphalt rock possible into the interstices of the stone without disturbing the latter.

As the work progressed the roller was kept moving back and forth parallel to the axis of the roadway and worked from the outer edge to the crown as in ordinary macadam construction. To prevent the adhesion of the bitumen to the wheels of the roller a light coating of natural cement was dusted over the rock asphalt, but it was soon found that in moving the roller off the work at the end of each rolling enough dust collected on the wheels to prevent adhesion and no more cement was used. The stone had not been thoroughly compacted before applying the asphalt, and for this reason a very perceptible wave in the surface preceded the roller, causing the asphalt to crack until after the fourth or fifth rolling. At this stage most of the coating had been forced into the voids of the stone, as was found by cutting into the surface, and very little decrease in its thickness was detected after the rock had come to a firm bearing. In this manner a section 385 feet long and 18 feet wide was paved.

The behavior of the rock asphalt varied according to temperature. During early morning, when both asphalt and rock were cold, it worked into hard, rounded lumps, which were broken with difficulty with the rakes. The location of such lumps was plainly visible after repeated rolling, but they disappeared completely after being subjected to the heat of the sun. As the day grew warmer the material spread smoothly and compacted evenly and uniformly. A light but cold rain, with temperature of 65° F., impeded work for several hours. After a temperature of from 70° to 75° F. was reached work progressed well and good results were obtained immediately. The temperature of the days during the period covered by the work was uniform, excepting at the time of the cold rain mentioned above, with a maximum temperature ranging from 94°

to 97° F. during the heat of the day. The inadvisability of working the material when chilled and damp was apparent, for that portion of the road laid at a temperature of 65° F. failed to become hard and firm for several hours after subsequent applications had compacted satisfactorily.

One difficulty met in this work was caused by the necessity for having one half of the roadway open to traffic, while the other half was under construction. In order to avoid a break or distinct line between the parts, the inner edge of the asphalt was rolled lightly, so that when the other half of the work was laid the loose particles would unite without difficulty. As a result of this precaution an unbroken surface along the middle of the roadway was secured. The ready cohesion of the particles was further shown when, after an accident, it was necessary to repair a portion which had been opened to traffic for three days. The asphalt and stone were removed over an area of 4 square feet, the stone replaced and tamped by hand, and a new coating of asphalt applied and rolled. After two days no evidence of damage or repair remained visible.

As soon as one-half of the roadway had been surfaced and properly rolled it was opened to traffic in the hope that the asphalt would be further worked into the voids of the stone by the action of wheels and hoofs. At first the coating rutted badly under the weight of the heavy loads of gravel and logs to which it was subjected and the smooth surface given by the roller was seriously cut by hoofs. This effect decreased visibly after three or four days; at the end of a week no trace remained of the deepest ruts and the surface had become smooth and compact. It then presented an appearance not unlike that of an asphalt pavement which has been open to traffic for some time. Close inspection, however, showed the presence of a slight excess of bitumen which held a thin film of dust and fine sand closely and caused it to become incorporated into the surface under traffic. With the passing of time this excess of bitumen disappeared and at the end of four months very little was noticeable.

The conditions necessary to satisfactory results from the use of rock asphalt in this form as a binder in macadam road construction are: That the broken stone of the wearing course be clean and dry to facilitate adhesion of the bitumen and of fairly uniform size and uncompacted to give a large percentage of voids; that the stone be spread evenly and true to grade; that the temperature of the atmosphere be sufficiently high to cause the bitumen to soften and allow the grains to glide over each other readily; that the asphalt be thoroughly raked into the voids of the stone without disturbing the latter.

The simplest method of rolling rock asphalt is to have the roller move forward as far as the work permits, returning with but little lateral change of course. Any great change in the course of the roller

accompanied by rapid guiding movement of the trunnion roll causes the loose asphalt to slough over the stone surface and tends to make it adhere to the trunnion roll. For similar reasons sudden starting, stopping, and reversing are to be avoided until the material has been thoroughly compacted. If the roller is driven upon newly spread material a distance less than its wheel base, at the same time working from the outside to the crown of the road, the drive rolls may always be kept upon partially compacted material. In this manner the rolling may be kept abreast of the spreading, little damage being done in case of rain or sudden cold, and any defects in the work will become apparent as the work progresses.

The stone, labor, teams, and roller were furnished by the county authorities. Labor ranged from $1.20 to $1.25 and teams cost $3 per day of ten hours. The roller was loaned to the county for this work and the cost of operating it was $2.50 per day for the engineer plus the cost of fuel. The water for the roller was taken free of charge from the city mains, but as a team was kept constantly to supply water and coal to the roller this amount is charged in the item of rolling. About 65 cubic yards of gravel was removed in shaping the subgrade and used to repair the gravel surface beyond the point where the work stopped. The cost of loading and hauling this material is charged against the asphalt work, while the spreading, rolling, and sprinkling of the gravel is charged against repair work in the preparation of the roadway to receive a treatment of oil. This item is referred to again in the discussion of the cost of experiments in the use of oil as a dust preventive. The unit cost of rolling is large in proportion to the actual cost of the roller to the county, by reason of the short length of road surfaced. As a consequence the roller was frequently idle, though under steam.

Two factors lent themselves to increasing the cost of spreading the asphalt: The inexperience of the laborers in working the material, and the long haul to which it was subjected. The former would have been materially reduced after a few days, but the latter was unavoidable and resulted in packing the rock asphalt so firmly that it required great additional labor afterwards to break the lumps. The stone was delivered on the roadway at $1.20 per cubic yard and was spread 4 inches thick uncompacted, making the cost per square yard delivered 13 cents. The rock asphalt was donated, but is charged in the following table at its market price of $5 per ton f. o. b. cars at Bowling Green, and the cost of loading and hauling it is included in its unit cost delivered on the work. It was spread about 1½ inches thick, or at a rate of 24.5 square yards per ton.

The following table contains an itemized statement of the cost of the various processes of the work:

TABLE 5.—*Cost data of rock asphalt experiment.*

Item.	Cost per square yard.	Total cost.	Percentage of total.
	Cents.	*Dollars.*	*Per cent.*
Shaping subgrade	5.66	43.60	11.8
Stone on work	13.71	105.60	28.8
Spreading stone	.78	5.97	1.7
Rolling stone	.09	.67	.3
Asphalt on work	23.77	183.10	50.0
Spreading asphalt	1.44	11.06½	3.1
Rolling asphalt	2.18	16.78½	4.3
Total	47.63	366.79	100.0

As has already been stated, the finished road surface was similar to an asphalt pavement which had been open to traffic for some time in its dark-brown color and smooth even finish. Practically little impression was made on the surface by traffic after a week, except on very warm days, and this was not sufficient to impair its appearance or value. Incisions into the surface revealed a dense coating of dust and sand about one-eighth of an inch in thickness thoroughly incorporated in the bitumen. This served at once as a wearing surface and as a protection to retain the bitumen in the sand below. Only at one or two points did the limestone of the wearing course protrude. This occurred where the rock had been disturbed after it had been rolled and had been forced up into the asphalt layer. Rolling and traffic had left it flush with the surface, however, and its presence was considered as a defect in the appearance rather than in the wearing quality of the roadway.

After four months the appearance of the roadway had undergone no appreciable change. Along the crown a few more particles of limestone were exposed to view. This was undoubtedly due in large measure to the effect of traffic in forcing the asphalt into the voids of the stone, for a large part of the traffic is confined to the center of the pavement. This development was not regarded as of serious consequence, however, as the rock along the axis of the roadway had been more or less disturbed while the asphalt was being laid, and it is probable that the few protruding stones were those which had been raised above the general plane of the rock surface and were not covered to the same depth by the rock asphalt as surrounding rock. Incisions into the asphalt at this time revealed no perceptible loss by drying or hardening of the bitumen, as the sand particles showed their normal inclination to move when warmed in the hand.

The permanence of macadam construction depends largely upon the nature of the binder used and the ability of traffic to supply by

attrition the material which is removed by wind and water. It was to test the adaptability of rock asphalt as such binding material that this piece of construction was undertaken. The pavement formed is dustless. There is no appreciable wear of the surface material to be raised and carried away by the wind as dust and such dirt as may be carried upon it is readily removed by sweeping or flushing with water. There is sufficient adhesive power in the bitumen to serve as a cement to hold the stone of the wearing course in place, giving at once a smooth and waterproof surface. It is resistant to deformation under a load, yet sufficiently plastic to break the severity of the blow from a horse's hoof, and thus, in a measure, avoids the harmful effects of rigid pavements on animals.

Observations will be continued to determine its resistance to wear and weathering and its general utility as a macadam binder.

OILS.

In connection with the work on rock asphalt experiments were made to determine the comparative value of a residuum oil preparation and crude oil as dust preventives. The oil preparation is a patented mixture of residuum oils combined with a view to obtaining such proportions of asphaltic and lighter oils as shall be best fitted for immediate dust laying and permanent improvement of the roadway. The crude oil was from Saltlick, Ky., and was a normal Kentucky oil with a semiasphaltic base. These tests were made on Cemetery pike beyond the point where the rock asphalt work ended.

The general condition of the gravel roadway was unsatisfactory for the purposes of such a test. The cross section of the roadway was quite flat, the crown having been completely worn down by continued use, so that lateral drainage was defective. There were also extensive pockets of loose material, characteristic of roads made of gravel containing a large percentage of sand and clay. An effort was made to repair these patches or pockets by removing the loose sand and fine gravel and filling them with new material which was then sprinkled and rolled. It was not considered advisable, however, to reshape the cross section of the roadway, for the reason that this would have required the loosening of the entire road surface and the addition of new material to bring it to grade and crown. In this reconstructed condition the gravel would have been very porous and insufficiently compacted to retain the body of the oil on the surface of the roadway.

Heavy rains had fallen for several days preceding the application of the oil, and although the road surface was quite dry there was a large amount of moisture in the roadbed. This prevented the rapid absorption of the oil by the gravel before the evaporation of the lighter oils took place.

The oils were applied over a width of 12 feet of the roadway by means of an oil sprinkler adapted to the uniform spreading of heavy liquids. The flow of the oils was regulated according to the needs of the roadway, dusty portions and newly repaired places being given more than the average section of roadway. As a consequence of this unequal application the roadway after oiling presented a uniform appearance.

The first material to be applied was the oil preparation. In order that none of this oil should be carried to the asphalt work a space of 500 feet was left untreated between the two sections. A tank load of 760 gallons was spread over an area of 841 square yards, giving an average of 0.903 gallon per square yard. At the time of application the temperature of the oil was 87° F., due to its exposure to the sun in the tank wagon. It was heavy and was absorbed very slowly by the gravel, about four days being required to cause it to become thoroughly incorporated into the surface of the road. After this time the gravel became compact and showed few traces of wheel marks except at points where repairs had been made, in which cases the cementing process took place more slowly.

In the case of the crude oil the application was first made on one side of the roadway to allow traffic to pass over the untreated side in order to avoid any harmful effect to rubber tires. The other half was then treated the following day. Being more fluid, it was absorbed more readily than the oil preparation, but its first behavior and effect were quite similar to the latter. In fact, there was no perceptible difference between the appearance of the two sections after four days had elapsed. The odor of the crude oil was slightly more pungent than that of the oil preparation. In all, five tank wagons of crude oil, or a total of 3,712 gallons, were applied to 4,416 square yards of road surface, making an average of 0.84 gallon per square yard.

In order to compare the effects of oil on gravel and on macadam roads an experiment was made on Scottsville pike, leading south from Bowling Green. This was a limestone macadam road 12 feet wide in good repair, laid on a Telford base. The traffic over this road was similar to the traffic over the gravel road. At the time of treatment there was a thin coating of about one-eighth inch of dust on the roadway, consisting largely of powdered limestone. This roadway was given an application of 755 gallons over an area of 1,452 square yards, making the rate per square yard 0.52 gallon.

A slight change in the method of treatment was necessary because of the high crown of this road, which was more than 1 inch per foot. The oil was not applied uniformly over the entire width, but instead a width of 6 feet in the middle was treated heavily while the edges were lightly oiled. Any excess of oil along the crown

flowed over the portions less heavily oiled and was absorbed before reaching the earth shoulders. This prevented a waste of the oil and placed the heaviest application on the part of the roadway subjected to greatest traffic. This roadway absorbed the oil more rapidly than did the gravel road. This was due to the lighter application, to the greater porosity of the soft limestone, and to the fact that the better lateral and longitudinal drainage of the macadam road had left it drier after rains.

The cost of applying the oil was slight because of the ease with which it was spread with the sprinkler. The tank car containing the crude oil was placed on a trestle siding in a coal yard and the oil drawn off by gravity, thus saving time and labor in pumping. A team and driver at $3 per day and an operator estimated at $2 per day were required to do the work. The relative decrease in the cost of application as the area treated increased, while the facilities for spreading the oil remained the same, is due to the fact that the additional time required to empty the tank wagon when the valves were partially closed was not at all proportionate to the increase in area covered; nor was this additional time a factor of importance compared with the longer time required to drive to and from the tank car to fill the sprinkler. The very low cost of application in the case of the macadam roadway was due to its short distance from the siding on which the tank car stood.

The repairs to the gravel road were referred to in discussing the rock asphalt work. The charge for this item includes the removal of worn-out material and the spreading, sprinkling, and rolling of the new gravel. Such ditching as was necessary is also included in this item. The following table gives a statement of the cost of repairs, materials, and application of the oils:

TABLE 6.—*Cost data of oil experiments.*

Experiment.	Item.	Cost per square yard.	Total cost.
		Cents.	*Dollars.*
Special oil preparation	Repairs and ditching	0.57	4.79
	Oil	.13	110.00
	Application	.47	3.93
	Total cost	1.17	118.72
Crude oil on gravel road	Repairs and ditching	.33	14.38
	Oil	4.46	196.94
	Application	.16	7.28
	Total cost	4.95	218.60
Crude oil on macadam road	Oil	2.75	40.00
	Application	.11	1.64
	Total cost	2.86	41.64

It is to be regretted that no statement can be made of the comparative results obtained from the application of the two oils. The entire area treated with the special oil preparation and about 1,100 square yards of that treated with the crude oil were covered with a coating of gravel in the fall, concealing the original road surface and all traces of the oils. Beyond the point where this gravel was laid down the crude oil was plainly visible and its effect marked. The surface gravel was closely knit together and all dust and sand particles were well coated with oil. The entire road surface presented a uniform appearance and there was no trace of the repairs made at the time of application. Rain had fallen just previous to the inspection and there was no dust, but it was evident from the appearance of the road surface that it was ordinarily quite dustless. Statements to this effect were also made by competent observers.

On the macadam road the effect of the treatment was less marked than on the gravel road. The discoloration was less pronounced and there were no oil-coated particles to be found because of the perfect absorption of the oil by the limestone dust. However, the effect of the oil could be seen in the wheel tracks where the dust coating was more closely compacted.

No complaints had been made that the oil caused injury to rubber tires, paint on vehicles, or to clothing; on the other hand, as soon as the wholesome effect of the treatment by oil became evident the city of Bowling Green took immediate steps to treat sections of streets within its limits subjected to the heaviest traffic. The results of such applications were reported to be entirely satisfactory.

FURTHER REPORT ON EXPERIMENTS MADE AT JACKSON, TENN., IN 1905 WITH TARS AND OILS.

TAR EXPERIMENTS.

An average quantity of 0.45 gallon of tar per square yard was used in this experiment. It was placed on the road at a temperature of from 160° to 190° F. The material used came from Alabama and was a by-product from the manufacture of coke. It was practically free from moisture.

The road on the levee to which tar was applied has suffered several breaks owing to a flood, in which case parts of the road were washed away entirely, though it is apparent that the application of tar prevented the washing away of the road surface on the portions that remain intact.

Street-car tracks are laid on the street forming one side of the city square. This street was treated with tar. Owing to improper ballasting of the tracks, sand and earth are constantly washed down upon this tarred surface. For this reason the success of this experi-

ment has been considerably lessened. All other places where tar was applied are still in excellent condition, with the exception of one street which sustains very heavy country traffic at all seasons of the year. This stretch of road is densely shaded and only a thin surface crust ever dries out. Wheels have picked up this thin crust and the tar has accordingly disappeared. No repairs have been made on the other streets which were treated with tar since the material was applied and the absence of mud or dust on these roads is noticeable. The dust is blown off the surface and the small amount of mud that forms is washed away by each rain. The results of these experiments with tar have been on the whole very satisfactory.

OIL EXPERIMENTS.

Several grades of oil were used in these experiments, varying in quality from a light crude oil to a heavy residuum. About 0.48 gallon of crude oil was applied per square yard and 0.71 gallon residual oil on a like area. The crude oil was used cold, but the others were heated.

No further treatment or repairs have been made to the roads which were treated with oils. A report from the city engineer of Jackson, Tenn., under date of February 25, 1908, states that the crude and steamer oils have left no appreciable effects, but that good results are still apparent where the roads were treated with the residual oils. These latter roads are still practically dustless and all washing has been prevented.

Approved:

JAMES WILSON,

Secretary of Agriculture.

WASHINGTON, D. C., *March 16, 1908.*

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United States Department of Agriculture,

OFFICE OF PUBLIC ROADS—CIRCULAR NO. 90.

LOGAN WALLER PAGE, Director.

PROGRESS REPORTS OF EXPERIMENTS IN DUST PREVENTION, ROAD PRESERVATION, AND ROAD CONSTRUCTION.

INTRODUCTION.

During the summer of 1908 a number of experiments in road preservation and construction were conducted by the Office of Public Roads in cooperation with various municipalities. It is the purpose of this circular to present a brief description of these experiments and also to report the results obtained from experiments conducted along similar lines in previous years. Complete descriptions of these earlier experiments will be found in Circulars Nos. 47 and 89. The experiments with asphaltic preparations, tar preparations, and residual oil made at Newton, Mass., in 1908 are reported on pages 2 to 10; the experiment at Independence, Kans., with earth-asphalt, on pages 10 to 12; and those with tar-slag, tarred slag, and tarred slag-limestone macadam made at Birmingham, Ala., on pages 12 to 15. Four experimental sand-clay roads built in Kansas are described on pages 15 to 19. Further reports on various experiments conducted by the Office in previous years will be found on pages 19 to 23.

It will be noted that the experiments with dust preventives and road binders made in 1908 differ from those of earlier years mainly with respect to the manner of application of the various dust preventives and road preservatives. While the earlier experiments were concerned with the surface treatment of old roads, the later ones deal principally with the treatment of roads during construction or reconstruction. It is the belief of the Office that where new roads are being built or old ones are being resurfaced it is far better policy to incorporate a suitable binder with the road material at that time than at a later period to attempt to prevent deterioration by means of surface applications when the surface is worn and dusty. While the initial cost of such work will, of course, be somewhat greater, it should prove more economical in the long run where proper materials are employed in a suitable manner.

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EXPERIMENTS AT NEWTON, MASS., IN 1908.

ASPHALTIC PREPARATIONS, TAR PREPARATIONS, AND RESIDUAL OIL.

The experiments at Newton, Mass., were conducted by the Office of Public Roads in cooperation with Mr. Charles W. Ross, street commissioner of Newton. All labor, apparatus, and road stone were furnished by the city of Newton. Some of the binding materials were donated by manufacturers and others were purchased by the city. Direction and supervision of the work were furnished by the Office of Public Roads.

Cabot street, running west from Center street and connecting Newton with Newtonville, was selected for all experiments excepting No. 11. This street had been macadamized to a width of from 19 to 25 feet about twenty years previously and was badly in need of resurfacing. The grade varied from 1.5 per cent to 6.35 per cent. This road is subjected to an ordinary mixed traffic in which automobiles predominate.

Crushed field and cobble stone was furnished for part of the work, but for the greater portion chlorite schist obtained from the city's quarry was used. The length of haul was considerable, four loads per team per day being the maximum and three loads the minimum. The laborers were for the most part skilled in road work and were furnished from the regular city force. The cost of labor per eight-hour day was as follows:

Common labor	\$1.75–\$2.25	Double teams	\$5.25
Foreman	2.50	Roller	10.00
Single teams	3.50	Roller operator	2.50

The cost of broken stone at crusher was figured at 93 cents per cubic yard, sand at 69 cents, and gravel at 7 cents. Account was taken of all miscellaneous expenses, such as lumber for stone gauges, wood for heating purposes, drayage, interest on capital invested in apparatus, etc., and divided among the different experiments. Of the various binders used the asphalt preparation was figured at 13 cents per gallon, oil and refined coal tar at 8 cents, and refined water-gas tar at 7½ cents. This included freight charges. As some of these materials were furnished free of charge, their cost could only be estimated, and for purpose of comparison can, if desired, be eliminated in considering the various experiments, provided the quantity employed is taken into account. In different parts of the country their cost would vary, so that for estimation of similar work done elsewhere the cost at the given location should be substituted.

Owing to the distribution of the laborers and their employment in various kinds of work during the same day, as well as to occasional losses of time which are unavoidable in experimental work, it was impossible to determine accurately the increased cost of construction

over that of ordinary macadam. As the average cost of macadam per square yard 1 inch in depth has in the past amounted to 10 cents in the city of Newton, it would seem fair to deduct this amount from the total cost and consider the remainder as additional cost. New material was applied to a finished depth of 4 inches, so that the total cost per square yard minus 40 cents will give a close approximation of the additional cost. The cost data of the different experiments are given on page 10.

All work was carried on during the months of August and September, the weather being cool. No bituminous material was mixed in wet weather, nor applied while the under surface was wet. With exceptions noted under the various experiments, the work in general was carried on as follows: The entire road was first spiked up and all stones over 3 inches in diameter removed by hand; soft places were filled with gravel and the road brought to a crown of one-half inch to the foot and well rolled with a 20-ton steam roller. A $2\frac{1}{2}$-inch course of crushed stone not larger than $2\frac{1}{2}$ inches in diameter was then spread on, water applied, and the whole rolled until compact and solid. A foundation of this kind was constructed as a base for all of the experiments. As soon as the base was thoroughly dry a $2\frac{1}{2}$-inch course of warm bitumen-covered stone was spread uniformly over the whole surface and rolled until firm. The surface was finished according to methods described under the different experiments.

The bitumen-covered stone was prepared at the crusher in the following manner: The bitumen was heated in two 2-barrel kettles to a temperature of about 225° F., and at this heat was sufficiently fluid to be applied. It was then dipped out in a gallon measure and poured over thoroughly dried and heated crushed rock. The quantity of rock was carefully gauged and the sizes proportioned as given under the different experiments. All mixing was done on a large wooden platform and the stone turned with long-handled shovels until perfectly covered. Two complete turnings were usually sufficient. The hot mixture was then hauled to the road and applied. The stone was heated on semicylindrical heaters, approximately 8 feet by $3\frac{1}{2}$ inches, closed at one end and fitted with smokestacks, wood being used as fuel. With a good fire, it was found that the stone became sufficiently hot to mix in a very short time, so that the operation of covering the heater with fresh stone and removing the hot stone was almost continuous. Two of these heaters were used for the large-sized stone and one for the small. In mixing, it was found advisable to first place a measured quantity of fine material on the platform and cover this with the proper amount of coarse material, after which the bitumen was applied. While being turned, each pile was carefully raked by a laborer equipped with an ordinary asphalt rake.

It was found most economical and convenient to mix batches of stone weighing approximately 1,300 pounds and to employ sufficient labor to mix two batches at one time. By proper arrangement of labor, 1 foreman and 15 men could thus mix 37 cubic yards of material per day.

The various binders were delivered in barrels and were exceedingly viscous liquids at ordinary temperatures. The asphalt and oil preparations could be run from the bung, but in some cases it was necessary to destroy the barrels containing the tar preparations in order to remove the contents. The results of examination of these various preparations are given in Tables 1 and 2.

TABLE 1.—*Properties of asphaltic preparations and residual oil.*

Kind of test.	Asphaltic preparations.	Residual oil.
Specific gravity 25° C./25° C	1.127	0.994
Flash point		473° F. (245° C.)
Volatilization tests:	*Per cent.*	*Per cent.*
Loss at 212° F. (100° C.) after 5 hours	1.35	0.25
Loss at 325° F. (163−° C.) after 7 hours	11.74	.85
Loss at 400°F. (204+° C.) after 7 hours	19.36	5.30
Residue	[a] 80.64	[b] 94.70
Distillation tests: [c]		
Distillate to 110° C., per cent by volume	([d])	
Light oils, 110° C. to 170° C., per cent by volume	4.9	
Heavy oils, 170° C. to 240° C., per cent by volume	26.3	
Soluble in CS_2 total bitumen	96.62	99.85
Organic matter insoluble in CS_2	3.18	.15
Inorganic matter	.20	.00
Total	100.00	100.00
Insoluble in CCl_4	8.61	
Insoluble in 90 per cent benzol	6.21	
Bitumen [e] insoluble in 86° naphtha		5.40

[a] Cracked; hard; brittle.
[b] Soft; semiasphaltic; pulled to thread.
[c] Distillate to 170°, when cold held about one-twelfth its volume of solids. Distillate 170° to 240°, when cold held a very small amount of solids. This distillate separated into two layers of oil, one apparently a petroleum and the other a tar product.
[d] Trace.
[e] Per cent total bitumen, 5.46.

TABLE 2.—*Properties of refined tars.*

Kind of test.	Coal tar.	Water-gas tar.
Specific gravity 25° C./25° C	1.221	1.165
Distillation tests:	*Per cent.*	*Per cent.*
Distillate to 110° C., per cent by volume	0.0	0.0
Total light oils to 170°C., per cent by volume	1.6	6.3
Total dead oils, 170° C.–270° C., per cent by volume	28.5	51.9
Pitch residue by difference	69.9	41.8
Total	100.0	100.0
Soluble in CS_2 total bitumen	81.71	97.47
Organic matter insoluble in CS_2	18.18	2.53
Inorganic matter	.11	
Total	100.00	100.00
Insoluble in 90 per cent benzol	18.48	5.34

When cold, the light oils from the coal tar contained about one-eighth their volume precipitated naphthalene, while only a trace of naphthalene was found in the water-gas tar distillate. The dead oils from the coal tar contained about one-third their volume precipitated naphthalene and from the water-gas tar about one-twelfth their volume. The residue from the coal tar was brittle and nonlustrous; that from the water-gas tar was brittle and lustrous.

Experiment No. 1.—Asphaltic Preparation.

Upon the base prepared as previously described a $2\frac{1}{2}$-inch loose coat of hot bitumen-covered stone was placed, and rolled with the 20-ton steam roller until firm. The use of a smaller roller weighing not over 8 tons would have been preferable, but none of that size could be readily obtained. In this experiment the stone and bitumen were employed in the proportion of 960 pounds of $1\frac{1}{2}$ to $\frac{3}{4}$ inch stone to 350 pounds of $\frac{3}{4}$ to $\frac{1}{4}$ inch stone to 5 gallons of binder. This mixture could be rolled while still hot without sticking to the roller, and when firm averaged 2 inches in depth. A light coat of stone screenings one-half inch to dust was applied in quantity sufficient to fill the surface voids, and the whole well rolled. The finished road while quite solid was, of course, not so dense as though a more carefully proportioned mineral aggregate had been employed. Stones of this size, however, were more easily mixed by hand with a less amount of binder than would have been required had a greater proportion of fine material been employed.

The section treated was 222 feet in length and averaged 23 feet in width, giving a total area of 567 square yards. The amount of binder per square yard amounted to 0.54 gallon.

Experiment No. 2.—Asphaltic Preparation.

In the section reserved for this experiment it was intended to use a mineral aggregate containing some material finer than one-fourth inch in diameter, in order to reduce the percentage of voids. At the time, however, conditions were such that in order to keep the laborers constantly employed it was found necessary to carry on the mixing at two different places. No fine material being available at one of these points, a mixture similar to that described in Experiment No. 1 was the best that could be obtained. At the other mixing plant the same formula was employed, with the exception that stone from $\frac{3}{4}$ inch to dust was substituted for that running from $\frac{3}{4}$ to $\frac{1}{4}$ inch. Alternate loads of the mixtures were applied to the road. Otherwise the experiment was identical to No. 1.

Three hundred and ninety feet by 23 feet and 109 feet by 19 feet of road surface was constructed in this manner, giving a total of 1,226 square yards. The binder consumed amounted to 0.54 gallon per square yard, as in Experiment No. 1.

Experiment No. 3.—Asphaltic Preparation.

This experiment was in every way similar to Nos. 1 and 2, excepting that all of the bituminous mixture was made up in the proportion of 960 pounds 1½ to ¾ inch stone to 350 pounds ¾ inch to dust to 5 gallons of bitumen. The stone running from ¾ inch to dust was used just as it came from the crusher. Shortly after consolidation a number of weak spots developed in all three of these sections and had to be patched with hot bitumen. This raised the total cost of each 0.99 cent per square yard.

A section 479 feet in length by 20 feet in width was treated in this experiment, giving a total of 1,064 square yards. The same amount of binder per square yard was consumed as in the preceding experiments.

Experiment No. 4.—Asphaltic Preparation.

Instead of a surface application of stone screenings as in Experiment No. 3, a coating of tarred sand was applied in this trial section in a quantity sufficient to fill the surface voids and produce a surface somewhat resembling sheet asphalt. Refined coal tar was used for this purpose and both it and the sand were heated before use. The additional cost of labor and material amounted to 5.86 cents per square yard; but the general appearance of the street was greatly improved, and it is believed that this surface will prove to be more water resistant and of better wearing quality than that produced in Experiment No. 3.

A section 93 feet in length and 20 feet in width was treated in this manner. The total area covered amounted to 207 square yards. A mixture of 0.5 gallon of asphaltic preparation and 0.18 gallon of tar was used upon every square yard so treated.

Experiment No. 5.—Asphaltic Preparation.

This section of road was treated like No. 3, with the exception that a flush coat of the hot asphaltic preparation was applied to the bitumen-covered surface before spreading the stone chips. This was done by pouring the material from buckets and while hot sweeping it into the surface with stiff long-handled brooms. Somewhat similar results could have been obtained with less bitumen by painting it upon the surface, but the other method was used in order to make sure that the voids were filled as completely as possible. An increase of 1.12

gallons per square yard thus occurred, and the cost, including that of labor and material, was raised 17.12 cents per square yard.

A section 98 feet in length and averaging 20½ feet in width was treated in this manner, the total area covered being 223 square yards.

EXPERIMENT NO. 6.—ASPHALTIC PREPARATION.

This experiment was similar in every respect to No. 5, with the exception that a flush coat of the hot refined coal tar was applied instead of the asphaltic preparation.

A section 33 feet in length and 24 feet in width, giving an area of 88 square yards, was treated in this manner, 0.54 gallon of asphaltic preparation and 1.14 gallons of coal tar being consumed per square yard.

EXPERIMENT NO. 7.—ASPHALTIC PREPARATION.

On account of the patching which was required in Experiments Nos. 1, 2, and 3, it was thought advisable to construct a section in the same manner as No. 3 with the addition of more bitumen. Six gallons was therefore substituted for 5 gallons in the formula for Experiment No. 3. The results were more satisfactory, as no patching was afterwards required. The cost per square yard was, however, raised 1.24 cents.

A section 232 feet in length and 24 feet in width was thus treated. The total area covered was 618 square yards, and 0.71 gallon of asphaltic preparation was applied per square yard.

EXPERIMENT NO. 8.—RESIDUAL OIL.

This experiment was similar to No. 7, excepting that the semi-asphaltic residual oil was employed in place of the asphaltic preparation. After construction the road was not quite so firm as the surface produced with the asphaltic preparation, owing to the lubricating properties of the oil. The surface was somewhat roughened by horses' hoofs, but otherwise appeared fairly satisfactory.

The section treated was 74 feet in length and 23 feet in width, or an area of 189 square yards. The oil consumed per square yard amounted to 0.79 gallon.

EXPERIMENT NO. 9.—REFINED WATER-GAS TAR.

In this experiment refined water-gas tar was used in the same manner and in approximately the same quantity as was described in Experiments Nos. 7 and 8 for the asphaltic preparation and oil. The resulting road was similar to that obtained from the use of the asphaltic preparation.

Ninety-three feet of roadway 25 feet wide, giving an area of 258 square yards, was treated in this manner, and 0.81 gallon of tar per square yard was consumed.

Experiment No. 10.—Refined Water-Gas Tar.

In this experiment the road was constructed as in Experiment No. 9, except that a coating of tarred sand was substituted for the top dressing of stone chips. The finished surface was similar to that described in Experiment No. 4 and resembled sheet asphalt. The same kind and quantity of sand and tar were used as in Experiment No. 4.

A section 326 feet in length and 24 feet in width, giving an area of 869 square yards, was treated in this manner. A total of 0.81 gallon of refined water-gas tar and 0.18 gallon of refined coal tar per square yard was consumed in this experiment.

Experiment No. 11.—Molasses-Oil-Lime.

For this experiment a section of Summit street running north from Bellevue street, and varying from a 4.3 to an 8 per cent grade, was selected. While subject to less traffic than Cabot street, it was badly in need of resurfacing and the same general method of preparing the base was therefore followed. The binding material for the upper course was composed of a mixture of molasses, oil, and lime.

In certain sections of the country considerable quantities of waste molasses or blackstrap are produced in the manufacture of sugar. This material has but few uses and is therefore sold at a low figure in the neighborhood of the sugar refineries where it is produced. It is of an exceedingly sticky nature and when combined with quicklime produces calcium sucrate, which upon standing sets into a dense, sticky cement. This cement is somewhat soluble in water and for this reason can not in its natural state be used in localities subjected to frequent rains. An attempt was therefore made to waterproof it by the addition of a semiasphaltic oil with which it would be emulsified for the time being. From laboratory experiments a combination of these materials was devised which gave indications of suitability as a road binder. As the policy of the Office has always been to further the use of local products in the construction and treatment of local roads whenever possible, it was thought worth while to construct a short experimental section of road, using this material as a binder in order to determine its practical value. In the neighborhood of Boston, blackstrap molasses is sold at a very much higher figure than in localities near where it is produced, so that the cost of construction of this section of road was much greater than it would be in those localities.

The binder was prepared in a large mortar box by first slaking 320 pounds of quicklime with 108 gallons of water. As soon as the lime was completely slaked, 92 gallons of molasses was added and thor-

oughly mixed with it, after which 50 gallons of the semiasphaltic oil was stirred in. While the preparation was still hot it was mixed with the graded stone in the same manner as has been described for the bituminous mixtures, except that in this case the stone was not first heated. Eighteen gallons was applied to every 1,310 pounds of stone, and the concrete thus produced was hauled to the road and laid as soon after mixing as possible. When rolled it produced a firm and resilient surface upon which heavily loaded teams produced no wheel marks one-half hour after it had been laid. Under the action of the roller a small portion of the oil came to the surface, so that a light application of stone chips was required to put the surface in good condition.

The section treated was 351 feet in length, 186 feet of which was 17½ feet wide and 165 feet 13 feet wide. The total area covered was 600 square yards, and 0.92 gallon of molasses, 0.5 gallon of oil, and 3.2 pounds of lime per square yard was used. The labor item was exceedingly high in this experiment because of the inexperience of the workmen in preparing and handling the material. The cost of molasses was figured at 11 cents per gallon and of lime at 60 cents per 100 pounds.

SUMMARY OF EXPERIMENTS CONDUCTED AT NEWTON, MASS.

Besides the experiments already described, one other was made on Cabot street, in which sand was used and covered with a very weak preparation of lime and molasses as a top dressing. This experiment proved a failure, and its description and cost are therefore not included in this report.

After three months' wear all of the sections which have been described are in good condition, so that it is impossible to compare them satisfactorily. If any comparison were made, however, those sections covered with tarred sand seem to be best, and that constructed with oil as a binder not quite so satisfactory as the others. After a winter's wear, the defects in the least satisfactory sections should become apparent, but among those which are in good condition at the beginning of spring it is possible that a much longer time will be required before a choice can be made. In regard to this, as well as all other work of an experimental character, it may be said that the cost was greater than that which would be involved in the construction of long stretches of road where the work could be arranged and carried out more systematically. Table 3 gives in condensed form the cost data of all of the experiments described.

TABLE 3.—*Cost data of experiments at Newton, Mass.*

Experiment No.	Binder applied.	Labor per square yard. On road.	Labor per square yard. Mixing.	No. 1 stone per square yard.	Graded stone per square yard.	Screenings per square yard.	Sand per square yard.
		Cents.	*Cents.*	*Cents.*	*Cents.*	*Cents.*	*Cents.*
1	Asphaltic preparation	20.23	6.76	4.46	5.40	1.00	....
2	.....do	20.23	6.76	4.46	5.40	1.00	....
3	.....do	20.23	6.76	4.46	5.40	1.00	....
4	Asphaltic preparation and coal-tarred sand	23.10	9.69	4.46	5.40	....	0.64
5	Asphaltic preparation with flush coat of same material	23.59	6.76	4.46	5.40	1.00	....
6	Asphaltic preparation with flush coat of coal tar	26.48	6.76	4.46	5.40	1.00	....
7	Asphaltic preparation	20.23	6.76	4.46	5.40	1.00	....
8	Residual oil	20.23	8.73	4.46	5.40	1.00	....
9	Water-gas tar	20.23	8.14	4.46	5.40	1.00	....
10	Water-gas tar and coal-tarred sand	23.10	11.07	4.46	5.40	....	.64
11	Oil, lime, and molasses mixture	26.96	9.02	2.75	7.01	.92	....

Experiment No.	Binder applied.	Binder per square yard.	Miscellaneous per square yard.	Patching per square yard.	Total cost. Per square yard.	Total cost. Entire section.
		Cents.	*Cents.*	*Cents.*	*Cents.*	*Dollars.*
1	Asphaltic preparation	6.97	1.11	0.99	46.92	266.04
2	.....do	6.97	1.11	.99	46.92	578.05
3	.....do	6.97	1.11	.99	46.92	499.23
4	Asphaltic preparation and coal-tarred sand	8.38	1.11	....	52.78	109.25
5	Asphaltic preparation with flush coat of same material	21.72	1.11	....	64.04	142.81
6	Asphaltic preparation with flush coat of coal tar	16.06	1.11	....	61.27	53.92
7	Asphaltic preparation	9.20	1.11	....	48.16	298.11
8	Residual oil	6.35	1.11	....	47.28	89.36
9	Water-gas tar	6.21	1.11	....	46.55	120.10
10	Water-gas tar and coal-tarred sand	7.62	1.11	....	53.40	183.70
11	Oil, lime, and molasses mixture	14.57	1.11	....	62.34	374.04
	Total	....	....	....	....	2,714.61

EXPERIMENT AT INDEPENDENCE, KANS., IN 1908.

EARTH–ASPHALT.

In this experiment an attempt was made to construct an earth-asphalt road with an artificial asphalt preparation having the following properties:

Specific gravity 25° C./25° C.		0.981
Penetration 77° F. (25° C.) No. 2 N, 5 sec., 100 gms		257.00
Loss at 212° F. (100° C.) after 5 hours	per cent	0.00
Loss at 325° F. (163—° C.) after 7 hours	do	.20
Loss at 400° F. (204+° C.) after 7 hours	do	1.01
Residue [a]	do	98.99

[a] The residue was practically the same as the original material.

Soluble in CS_2 total bitumen	per cent	99.62
Organic matter insoluble in CS_2	do	.15
Inorganic matter	do	.23
Total	do	100.00
Bitumen insoluble in CCl_4	do	0.00
Insoluble in 86° naphtha	do	[a] 20.26

This material was used at the request of the manufacturers. A more suitable product could have been obtained by cutting it with crude oil or with a volatile distillate in sufficient quantity to insure a proper absorption by and better mixing with the soil.

Tonopah street, running the length of two city blocks, and Minnehaha street, for three blocks adjoining it, were selected for this experiment. A treatment of some sort was most urgently required, as these streets were almost impassable during winter weather. Tonopah street for a length of 300 feet was composed of a slate-colored gumbo which proved very difficult to work. The remaining 500 feet consisted of a buckshot clay which pulverized rather easily. With the exception of a few spots of gumbo, Minnehaha street was composed of disintegrated shale and argillaceous sandstone. Before treatment both streets were graded by city contract and this cost is not included in that of the experiment.

The artificial asphalt was furnished free of charge by the manufacturers at their plant, about three-fourths of a mile distant from the road. It was delivered at a temperature of about 400° F. and run into a tank wagon made by mounting a small boiler, 8 feet in length by 4 feet in diameter, upon a farm wagon. In this way no expense was incurred for heating. The material was sprinkled upon the road at a temperature of about 350° F. by means of a 3-inch gas pipe 6 feet long with one row of one-half inch holes bored at a distance of $1\frac{1}{4}$ inches from each other, and two rows of one-fourth inch holes similarly spaced. This device was fitted to the outlet of the boiler and rested about one foot above the surface of the road and at right angles to its length. Considerable difficulty was experienced in keeping the holes from becoming clogged, even when the outlet valve was wide open.

The road was plowed to a depth of 6 inches and the earth pulverized as completely as possible with a disk harrow and plank drag. It was found impossible, however, to pulverize the gumbo satisfactorily. The asphalt was applied at the rate of three-fourths of a gallon per square yard, after which the road was well harrowed and more asphalt applied as before. The road was again well harrowed and the earth and asphalt moved back and forth across the road with a

[a] Per cent total bitumen, 20.34.

grader, this method of mixing proving most satisfactory of any that was tried. The road was then plowed to a depth of about 5 inches, pulverized, and asphalt applied and mixed as before, after which water was put on until the road became quite muddy. Mixing was continued for some time with the road grader and disk harrow. An attempt was made at this point to use a tamping roller for mixing, but this had to be abandoned, as the spaces between the teeth became completely filled by the time it had traveled 300 feet. The road was left in this condition until it became fairly well dried out, when the tamping roller was tried again. A hard crust had formed on the surface of the section of gumbo and very little good was derived from tamping. The road was then shaped and rolled with an ordinary roller. It was found that the asphalt was not readily absorbed by the soil. Recent heavy rains, however, caused a finished portion of the road to become fairly muddy and traffic then seemed to produce an excellent mixing, so that in time the road may improve. The cost data for the 5,218 square yards constructed will be found in Table 4.

TABLE 4.—*Cost data of earth-asphalt road, Independence, Kans.*

Item.	Total cost.	Cost per square yard.	Item.	Total cost.	Cost per square yard.
Preparing road for asphalt	$29.00	$0.00556	Loading and unloading roller	$6.00	$0.00115
Applying asphalt	50.20	.00962	Asphalt [a]	1,243.95	.23840
Mixing on road	83.20	.01595			
Tamping and rolling	43.40	.00831	Total	1,474.15	.28251
Sprinkling with water	18.40	.00352			

[a] The cost of the asphalt was estimated at $20 per ton, and for this purpose the weight per gallon at temperatures 410° F. to 440° F. was calculated at 7½ pounds. The amount of asphalt per square yard at the temperature applied was 3.18 gallons, or at 60° F. was 2.98 gallons. At the latter temperature 1 gallon of the asphalt was found to weigh 8 pounds.

EXPERIMENTS AT BIRMINGHAM, ALA., IN 1908.

TAR-SLAG, TARRED SLAG, AND TARRED SLAG-LIMESTONE.

All experiments at Birmingham, Ala., were made on a road known as the Duck Pond road. This is the shortest route from Birmingham to Ensley, and the road is subjected to a very heavy traffic of drays and automobiles. In these experiments the old road was entirely reconstructed. A 24-foot tar-treated macadam with 5-foot shoulders was built and the grades were reduced to less than 5 per cent. The materials employed were blast-furnace slag, limestone, and tar. The slag was produced at the neighboring town of Bessemer. It was hard and acidic in character and contained a large percentage of glass. The limestone was quarried and shipped from a point about 40 miles south of Birmingham. The tar was obtained from

by-product coke-ovens and was produced at a low temperature. It had the properties given below:

Specific gravity, 25° C./25° C	1.169
Ammoniacal water, per cent by volume	3.1
Total light oils to 170° C., per cent by volume	16.3
Total dead oils, 170°–270° C., per cent by volume	30.7
Pitch residue by difference, per cent by volume	49.9
Total	100.0
Pitch residue, per cent by weight	55.0
Insoluble in 90 per cent benzol, per cent	6.7

This was a crude coal tar, and when cold about three-fourths of both light oils and dead oils solidified. The pitch residue was dense, lustrous, and brittle at ordinary temperature. Had it been practicable to distill off the ammoniacal water and total light oils a much more suitable product would have been obtained for this kind of work.

Experiment No. 1.—Tarred Slag-Limestone Macadam.

In this experiment a section 750 feet in length was constructed in three courses. The first course was composed of slag as it comes from the pit, placed 5½ inches deep at the center and 4½ inches deep at the edges. After rolling, a second course of the same material was laid 4½ inches deep at the center and 3½ inches deep at the edges. This course was also rolled, after which slag screenings were applied and rolled in. It was noticed that the slag by itself did not bond even when rolled after a heavy rain. After the road had become thoroughly dry, the tar was heated in a 2-barrel kettle and applied at a temperature of about 175° F. It was poured over the surface at the rate of 1 gallon per square yard by means of common watering pots, fitted with fan-shaped nozzles. A light course of limestone screenings was then spread over the tar to prevent it from sticking to the roller. The tarred surface was rolled until consolidated as well as possible. The lower courses, however, waved and tended to disrupt the surface bond if rolling was carried on for too long a time.

Experiment No. 2.—Tarred Slag-Limestone Macadam.

For Experiment No. 2 a section 2,300 feet in length was selected. The first course was laid as in the previous experiment, but the second was composed of 1 to 1½ inch crushed limestone, placed 4 inches deep at center and 3 inches deep at the edges. After being rolled, a third course of one-half to 1 inch crushed limestone was

applied to the depth of 1 inch and rolled until smooth. The tar was then applied as before. After standing for a few days, limestone screenings were applied and rolled in.

EXPERIMENT NO. 3.—TARRED SLAG MACADAM.

In Experiment No. 3 a section 450 feet in length was treated in the same manner as in No. 1, except that the second course was composed of crushed slag which had passed a 1½-inch screen and been retained by a 1-inch screen. This section required the same amount of slag screenings as the first and the immediate results were quite similar. Sections cut from this road showed that the tar had penetrated for about 1½ inches and that the voids in the lower courses had been well filled with fine material.

EXPERIMENT NO. 4.—TARRED SLAG MACADAM.

Experiment No. 4 was made upon a section 900 feet in length, the first two courses of which were laid and rolled in the same manner as was described for No. 1. Tar was applied as before and slag screenings spread after the tar had stood for two or three days. As this was the last part of the road to be constructed, and as the weather conditions at that time were exceedingly unfavorable, it was found impossible to finish the section satisfactorily. A length of 175 feet of this section was treated, however, with a second application of tar at the rate of 0.51 gallon per square yard and produced better results.

EXPERIMENT NO. 5.—TAR-SLAG MACADAM.

In Experiment No. 5 a section 100 feet in length was constructed in the same manner as in No. 3, with the exceptions that the second course was only one-half as thick and that a hot mixture of slag and tar was applied to the first course in sufficient quantity to bring the surface to the same grade as in the adjoining section. Slag screenings in the proportion of 25 per cent were added to the coarse slag while being mixed with the tar, and 16 gallons of tar was mixed with every cubic yard of slag. The tar and slag were both heated and mixed in a mastic kettle. Owing to the same conditions as have been described under Experiment No. 4, the results were not satisfactory. The cost data for these experiments will be found in Table 5.

TABLE 5.—*Miscellaneous data of experiments at Birmingham, Ala.*

Item.	Cubic yards.	Cost per cubic yard.	Square yards.	Cost per square yard.[a]	Total cost.
Excavation	20,876.3	$0.2268		$0.395	$4,735.74
Drains and clearing				.027	320.60
Slag placed on road (slag and stone sections)	1,167.57	1.0000	6,133	.190	1,167.57
Stone placed on road	1,043.9	2.2634	6,133	.385	2,362.53
Slag placed on road (slag section)	2,918.93	.99932	5,867	.497	2,916.95
Tar[b]				.044	526.60
Application of tar			12,000	.007	89.52
Engineer, rolling, and repairing machinery				.033	392.00
Coal, oils, repairs, sprinkling, etc				.038	460.04
Watchman				.023	279.50
Total					13,251.05

[a] The average total cost per square yard was $1.10.
[b] The number of gallons of tar applied was 13,700, at a cost of $0.0384 per gallon.

EXPERIMENTS MADE AT GARDEN CITY, DODGE CITY, BUCKLIN, AND FORD, KANS., IN 1908 WITH SAND-CLAY.

In the semiarid portions of Kansas and Nebraska there is an extensive area of sand hills. These hills are usually parallel to the rivers and vary in width from a few hundred yards to several miles. They are continually shifted by the winds, and hence road building in this region is a difficult problem. Good road material is scarce and the country is sparsely settled. In many localities there are no road materials except an alkali soil, gypsum clay, or a gumbo-like sedimentary clay.

EXPERIMENT AT GARDEN CITY, KANS.

At this point sand hills run parallel to the Arkansas River on the south side and form a strip nearly 7 miles wide. A careful inspection of the vicinity revealed no available road material except occasional deposits of gypsum clay distributed irregularly across the sandy belt. From two of these deposits was taken the material used in the construction of the road at this place. The first pit was opened about 900 feet east of the road and the other near the roadside. From the first pit 68 cubic yards was hauled, but it was then abandoned because of the distance of haul and because the clay showed a lack of binding power. The road was completed with material from the second pit. The farther down in the pit the stickier was the clay and the better it compacted after the addition of sand.

The problem to be solved in this case was the best method of handling the local material, gypsum clay, so as to produce a road with a wearing surface capable of resisting the action of the constant winds, which are generally from the south. For this experiment a section of road 765 feet long, situated on the slope of a sand hill, was selected.

The clay was hauled directly upon the road, down the center of which a width of 12 feet had been staked. The clay covering was

spread to a depth of about 9 inches immediately after it had been dropped on the road. The clay was hauled over the loads previously deposited and all holes so made were filled at once. Traffic was allowed upon it and this compacted the clay firmly. During the time of hauling the clay no rain fell, but after the hauling was completed a heavy rain soaked the clay and the road was finished as follows: While the road was wet a spike-toothed harrow was put on and the clay completely pulverized. Then five furrows were backfurrowed on each side of the clay, thus raising the sand shoulders above the clay center. A split-log drag was now put on the road and the sand thus raised by plowing was pulled from the shoulders upon the clay and thoroughly incorporated. The road was then smoothed and left for travel.

While the construction of this road followed closely the ordinary method of sand-clay construction, still there were some variations, owing to the peculiar conditions to be met, as has already been explained. It was believed that a surface was necessary which would resist the occasional heavy showers incident to this climate and at the same time the action of the winds. Therefore the clay having the greatest tenacity was selected. Because of the dryness of the climate it was deemed best to proportion the clay far in excess of the sand. While the clays available may not be altogether desirable, still any clay that will pack under traffic will improve greatly the heavy sands found in this locality.

The cost data of this experiment follow, and also the miscellaneous details of all four sand-clay experiments (Table 6).

Stripping clay in pit	$7.17
Plowing up clay in pit	10.50
Loading clay into wagons	33.00
Hauling clay to road	39.50
Spreading clay on road	10.00
Sanding, harrowing, and finishing road	2.33
Cost of clay on road per cubic yard	.40
Cost per square yard of part clayed	.10
Rate per mile	707.45

TABLE 6.—*Miscellaneous data of sand-clay experiments.*

Place.	Length of road treated.	Entire width of road.	Width of clayed part.	Depth of clay layer.	Clay hauled to road.	Surface clayed.
	Feet.	*Feet.*	*Feet.*	*Inches.*	*Cu. yds.*	*Sq. yds.*
Garden City	765	30	12	9	256	1,020
Dodge City	9,750	30	14	*a* 11	3,703	15,167
Bucklin	4,271	30	14	12	1,883	6,644
Ford	350	30	16	13	179	622

a Depth of clay and sand.

EXPERIMENT AT DODGE CITY, KANS.

The same natural conditions exist here as at Garden City, and the sand hills are on the same side of the river, though only 2 miles wide. A section of the road leading to Mineola, Kans., was selected, and after the work was started the citizens became much interested and urged that the entire 2 miles be hard surfaced. This was done.

The general plan of construction at this place was similar to that at Garden City. A deposit of clay was found near the middle of the section to be improved, formed from silt from an old irrigation ditch no longer in use. The water had been allowed to run into a large basin, and about 4 acres were covered to a depth of 18 inches with this fine silt. It had thoroughly dried out, so that when plowed up it was in excellent shape for handling with shovels. This material was almost gritless and became very sticky when wet. Although this may be regarded as an unusual condition in this locality, nevertheless results may prove it expedient to use a river silt for road purposes in other irrigation districts when practicable. If this material had not been found the road would have cost fully 50 per cent more.

The entire roadway was 30 feet wide. In the center of this a 14-foot track for clay was laid out by plowing two furrows 14 feet apart. The dirt was thrown out toward the side gutters. Beginning at the middle, the 14-foot part was plowed by backfurrowing the dirt toward the center. This formed a crown in the middle of the part to be clayed. Next, this was harrowed and the subgrade completed with a small grader. The shoulders were then made by running a furrow outside the subgrade and backing up the first furrow on each side. Two more such furrows were run, and in this way the shoulders were formed at least 10 inches higher than the subgrade. If the cross section is level, a toothed harrow is excellent to prepare the subgrade after it has been plowed as has been described above. When it is necessary to move material from one side to the other, or to carry material along in the subgrade, a 2-horse grader will be found useful.

After the subgrade had been prepared the clay was hauled and dropped three loads abreast. The center loads followed the center line exactly, and to this end a line of center stakes was set 200 or 300 feet in advance of the clay hauling. It was then an easy matter to drop the side loads properly. It is best to keep the center loads 30 to 50 feet in advance of the side loads. In this way three teams may be kept busy at the same time. In order to get a sufficient sand covering upon the road, drag scrapers were used and sand hauled from beyond the borders of the roadway. It was then spread with a harrow and a 2-horse grader evenly over the road and mixed with the dust and fine particles of clay. After a rain the sand was quickly in-

corporated with the clay. Still more sand was evidently needed, and this was harrowed into the clay as the mass dried and packed under travel. Finally, a large grader was used to shape the road.

As has been stated above, the clay at this place was rather more of an accident than a natural condition of wide extent; still it is of sufficient importance to justify a careful study of its behavior on the road. It would be an easy matter to provide settling basins along irrigation canals where this fine silt could be collected, and after the water had been shut off the clay thus deposited could be hauled upon the road. In this way large quantities of material could be provided, and if its use proves as valuable as indications seem to show, much good may be expected from this source in the improvement of heavy sand roads along irrigation ditches. In this experiment the silt combined readily with the sand when wet and held it firmly. The addition of sand took away its sticky qualities.

The cost data of this experiment follow:

Foreman for job	$51.50
Excavation (2,539 cubic yards)	396.69
Shaping subgrade	70.00
Plowing up clay	54.875
Loading clay into wagons	470.00
Hauling clay to road	608.38
Spreading clay on road	93.00
Harrowing and mixing clay and sand	6.00
Sanding road and building shoulders	107.685
Dressing road with grader	27.00
Work on bridge, timber, etc	59.53
Repairs, water boy, and sundries	52.75
Cost per square yard of part clayed	.138
Rate per mile	1,135.83

EXPERIMENT AT BUCKLIN, KANS.

For this experiment a portion of the road leading from Bucklin to Spearville was selected. It was on the south side of the Arkansas River, as in the preceding cases. The general plan of construction was identical with that used at Dodge City, but the clay was of a different quality. At the south end of the road a clay was used which proved to be a kind of buckshot. It hardened well, although the surface appeared to be of a loamy character and blistered badly at first, though later it packed and gave promise of durability. After removing the surface of the clay pit to a depth of 12 inches the character of the clay changed materially and it promised to be an excellent road material. At first it was feared that it might lack the necessary binding power, but as it was the only material within a mile of the road its use was begun as an experiment. When the pit was lowered 30 inches the clay became excellent in quality. This pit was located at the

highest point on the road and its use proved a great economy because of the ease of haul. From a place near the other end of the road an alkali clay was hauled upon the sand at that end. A section 6,771 feet long was laid out and plowed and the subgrade shaped ready for the clay. Of this distance, a section 4,271 feet long was improved and a section of 2,500 feet left to be improved by the community.

Following are the cost data of this experiment:

Foreman for job	$50.00
Excavation (1,584 cubic yards)	224.07
Shaping subgrade	32.37
Plowing up clay in pit	16.75
Loading clay into wagons	235.75
Hauling clay to road	304.875
Spreading clay on road	44.625
Repairs, etc	40.92
Cost per square yard of part clayed	.14
Rate per mile	1,183.64

EXPERIMENT AT FORD, KANS.

At Ford a short section forming the south approach to the bridge crossing the Arkansas River was graded and clay added. This was really a matter of grading an incline to the bridge, but as the material for the approach was sand it was necessary to form a hard top surface. This was done by adding clay. The material was gotten from a valley basin where clay had settled. The section of road treated was 350 feet long, and a bed of clay 16 feet wide and about 12 inches deep was put on. The surface was then covered with sand 2 inches deep and left for traffic to mix. It was frozen hard when placed on the road.

Some of the cost details follow:

Filling up and widening road	$17.25
Plowing, loading, and hauling clay	10.50
Spreading clay	8.00
Sanding clay	8.00
Dressing road with grader	.50
Total cost	104.25

FURTHER REPORT OF EXPERIMENTS MADE AT WAYLAND, MASS., IN 1907 WITH CRUDE TAR, TAR PREPARATIONS, AND OIL EMULSIONS.

These experiments are described in Circular 89, published in March, 1908. Thirteen experiments were made with water-gas tar, crude coal tar, and refined coal tar, and two with semiasphaltic oil emulsions. In all experiments but one, surface applications of the materials were made. The treated sections were last inspected in September, 1908,

about thirteen months after treatment. It should be noted that the winter of 1907–8 was a most severe one from the standpoint of road work, the ground being subjected to numerous and rapid freezings and thawings.

EXPERIMENTS NOS. 1, 2, 3, AND 4—WATER-GAS TAR.

All four of the sections treated with this material appeared about the same when inspected. The tar had disappeared from the road surface to a great extent, although the sections were in moderately good condition and fairly free from dust. These experiments have demonstrated that crude water-gas tar is valuable only as a temporary binder, and that the most satisfactory and at the same time most economical results can best be obtained by sprinkling the road with light applications whenever the dust becomes excessive.

EXPERIMENTS NOS. 5, 6, AND 7—CRUDE COAL TAR.

On the sections painted with crude coal tar, Experiments Nos. 5 and 6 were in fair condition. The tar had disappeared from some places and the road looked patchy. There was little dust, however, on these sections. The section similarly treated in Experiment No. 7 was in a much worse condition, although better than before treatment. It was located in the center of the town, where traffic conditions were more severe than on the other sections. Much of the tar had disappeared from the center of the street. It was somewhat dusty, and on the whole not very satisfactory. It was found necessary to make repairs on this section during the winter on account of heaving of the surface caused by freezing.

EXPERIMENTS NOS. 8, 9, AND 10—WATER-GAS TAR AND COAL TAR.

The results of Experiment No. 8 were in every way similar to Nos. 5 and 6. In this experiment separate applications of water-gas tar and coal tar had been made, though no additional benefit resulted from the use of the water-gas tar. In Experiments Nos. 9 and 10 a mixture of coal tar and water-gas tar had been applied cold, pea stone being used as a surface dressing for No. 9 and gravel for No. 10. At the time of inspection No. 9 was in slightly better condition than No. 10, although much of the tar had disappeared from both sections. These sections were, however, quite free from dust. It is evident that a mixture of this sort may be considered as a semipermanent binder, giving nearly as good results as crude coal tar and having the advantage of suitability for cold application.

EXPERIMENT NO. 11—SPECIAL TAR MIXTURE.

The section treated with this material, while subjected to the same conditions as No. 7, was in somewhat better shape, although by no means satisfactory. It was not free from dust when inspected, but was in much better condition than before treatment. No repairs were required on this section during the winter, although No. 7, adjoining it, had to be patched.

EXPERIMENTS NOS. 12 AND 13—SPECIAL TAR PREPARATION.

In Experiment No. 12 a section of road was resurfaced and the tar preparation applied according to the penetration method. This section was in almost perfect condition when inspected, being well bonded, nonslippery, and dustless. On the whole, this was the most satisfactory experiment made.

In Experiment No. 13 the same preparation was applied to the surface of a section of road already in good condition. With the exception of Experiment No. 12, it appeared at the time of inspection better than any of the others, being firm and dustless. A few spots, however, showed signs of disintegration, which will probably spread rapidly unless repaired.

From these experiments it is evident that a properly refined coal tar is to be greatly preferred to a crude tar. In the experiments reviewed the more lasting results obtained from the former may be accounted for mainly by the absence of ammoniacal liquor and the lower percentage of naphthalene and free carbon, as shown by analysis. In regard to all of these experiments, it may be said that the test was a most severe one, as explained in Circular 89, and that had conditions been normal much better results would have been obtained from those experiments which proved the least successful.

EXPERIMENTS WITH OIL EMULSIONS.

Two semiasphaltic petroleum emulsions were used as temporary binders in these experiments, and the method of application was described in Circular 89. On the section treated with emulsion No. 1 no residue could be discovered at the time of inspection, but traces of the oil were apparent on the section treated with emulsion No. 2. It was reported by residents along these sections that the road remained free from dust for eight months, which was very satisfactory, considering the amount of material applied.

FURTHER REPORT ON EXPERIMENTS MADE AT WASHINGTON, D. C., IN 1907 WITH CALCIUM CHLORIDE.

A report of this experiment will be found in Circular 89. Solutions of calcium chloride were sprinkled upon a trap macadam covered with a soft, dust-producing limestone binder. Three applications were made during the summer, and the salt retained by the road surface occasionally fed with water. The results were, of course, only temporary, but the dust was well laid and raveling prevented. No visible effect is apparent at the present time, as the road has since been resurfaced.

FURTHER REPORT ON EXPERIMENTS MADE AT BOWLING GREEN, KY., IN 1907 WITH ROCK ASPHALT, CRUDE OIL, AND A SPECIAL OIL PREPARATION.

A full report of these experiments will be found in Circular 89. The materials used were Kentucky rock asphalt, crude Kentucky petroleum, and a specially prepared residual oil. The results of an inspection made in January, 1909, are given below.

ROCK-ASPHALT EXPERIMENT.

In this experiment the rock asphalt was used as a binder and to fill the voids of a fresh macadam surface. It was first inspected after a light shower and found to have kept the water from the foundation very well, as evidenced by its damp surface in comparison with that of an untreated section adjoining, which had absorbed the water and already become dusty. A small quantity of loose material appeared on the surface, but this had evidently been tracked on from the untreated section. The entire road was smooth, free from ruts, and in only two small places could the underlying limestone be seen. These places were, however, just as well bonded as the rest of the surface and in no way inferior to it. On one side of the road the shoulder had settled slightly, leaving a raw edge open to attack from traffic and wash. By raising and consolidating this shoulder the road could be put in almost perfect condition.

OIL EXPERIMENTS.

The section treated with the residual oil had been, through mistake, completely covered with gravel shortly after its application, and no result whatever was obtained from its use. As in the Jackson, Tenn., experiment, the use of crude oil on both gravel and macadam roads proved to be of only temporary effect. No trace of the oil was apparent at the time of inspection, but, according to a statement made by the city engineer, the amount of dust on these roads in comparison with untreated roads was perceptibly lessened until

the latter part of the summer. It might be noted that as a result of these experiments the city of Bowling Green has, during the past summer, treated nearly all of its streets with oil. and considers the work satisfactory.

FURTHER REPORT ON EXPERIMENTS MADE AT JACKSON, TENN., IN 1905 WITH TARS AND OILS.

The original report of these experiments will be found in Circular 47, published in May, 1906, and a report of the condition of the sections when inspected in February, 1908, in Circular 89. When last inspected, in January, 1909, the following results were reported:

TAR EXPERIMENTS.

Of the city streets treated with a surface application of coke-oven tar, one is still in good condition, excepting a section about 20 feet wide, which has become worn by traffic until small depressions and holes about 10 inches in diameter and one-half to 1 inch deep appear at intervals of about 8 feet. This section had only one coat of tar applied in August, 1905, and has not been repaired since that time.

On the streets which were similarly treated where car tracks occupy the center the results are not so good, owing to the condition of the tracks, which were poorly ballasted. Mud and water are consequently washed over the road surface, and in this way deterioration has been caused to the tarred surface.

The sections which were treated with a second application of tar in 1906, one year after the first, are in excellent condition, and very little deterioration is noticeable.

On the section where the stone had been spiked up and tar mixed with it to a depth of 3 or 4 inches the results have not been so satisfactory. This is due to the fact that during hot summer months, when the tar softens, depressions have formed which prevent perfect drainage.

OIL EXPERIMENTS.

On the streets treated with residual oils the oil is in evidence only near the gutters, where the traffic has been light. On the other hand, on the section of country road treated in the same manner this oil is plainly visible over the entire surface. During the past summer it has proved very beneficial to the road by preventing raveling, which has occurred on the untreated sections. Very little dust is in evidence on the road and no washing is noticeable.

Approved:

James Wilson,

Secretary of Agriculture.

Washington, D. C., *March 25, 1909.*

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Issued March 19, 1910.

United States Department of Agriculture,

OFFICE OF PUBLIC ROADS—Circular No. 91.

LOGAN WALLER PAGE, Director.

SAND-CLAY AND EARTH ROADS IN THE MIDDLE WEST.

BY

W. L. SPOON, C. E.,

Superintendent of Road Construction, Office of Public Roads.

WASHINGTON:

GOVERNMENT PRINTING OFFICE.

1910.

LETTER OF TRANSMITTAL.

U. S. Department of Agriculture,
Office of Public Roads,
Washington, D. C., January 19, 1910.

Sir: I have the honor to transmit herewith the manuscript of a circular by Mr. W. L. Spoon, a superintendent of road construction in this Office, entitled "Sand-clay and Earth Roads in the Middle West." This publication gives the results of experiments planned in this Office and conducted in Kansas and the surrounding country in 1908. Already great interest has been manifested in this publication, and I therefore respectfully request that it be issued as Circular 91 of this Office.

Respectfully,

Logan Waller Page,
Director.

Hon. James Wilson,
Secretary of Agriculture.

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SAND-CLAY AND EARTH ROADS IN THE MIDDLE WEST.

INTRODUCTION.

Although the sand-clay method has been extensively used throughout the Southern States and has proved a great blessing in the betterment of the roads, until recently no attempt had been made to use this method either in the North or the West. In the North it was thought that the frost was too severe for that type of construction. It was also thought that there was a lack of clay or sand suitable for the work. In this matter the Office of Public Roads took a deep interest and planned a careful, systematic investigation and study of the road problem, and the conditions bearing thereon, throughout the Middle West. The general character of the formation of that section was studied and experimental roads were constructed by the sand-clay method in various sections with the materials which were to be had locally or within a permissible hauling distance. So great has been the success of this effort that a popular demand is made for the information and method to be made public. To meet this demand the Office of Public Roads has prepared this circular.

SOIL CONDITIONS.

As a matter of order it may be expedient to classify the soil conditions as they are found in the several localities, discuss each separately, and then describe a method of road improvement applicable to each.

GUMBO, "BUCKSHOT," OR BLACK WAX.

This type of soil has the characteristic of readily absorbing water and becomes very sticky when wet. As a rule it quickly dries out when the sun shines and, if dragged with a split-log drag, it soon becomes hard and smooth. It returns, however, to its original plastic and sticky condition when rain softens it. While the drag has done great good, there still remains need of improvement in order to render the road good and passable for all travel at all seasons of the year. This gumbo is a sedimentary formation and covers an extensive territory in the valley of the Mississippi and its tributaries. It is composed chiefly of aluminum silicate, with a little iron, and usually

carries a considerable quantity of organic matter. It is very fertile, supporting a luxuriant growth of vegetation, and is therefore exceedingly valuable as agricultural land. The question of good roads in such a locality is consequently vital. Gumbo has been burned to a clinker for road purposes with satisfactory results, but the process of burning is applicable only to localities having an abundance of cheap fuel. Under all other circumstances the cost of burning gumbo for a road surface is too expensive for practical application. A further study of the subject is therefore warranted, since a treatment for the betterment of this type of soil as a road material is a necessity. Agricultural interests demand it. Before attempting to say what this type of soil needs to make of it a better road, it may be well to study its physical characteristics and history.

The type of soil commonly known as "gumbo" is a gritless silt deposited by slow sedimentation from quiescent rivers, lakes, or other standing water. The particles composing gumbo are so very fine that they remain suspended for a long time and settle only when agitation ceases. Such a silt is now being carried by all the rivers east of the Rockies and west of the Mississippi River. This is demonstrated by the fact that each overflow leaves a gumbo sediment. By this process of separation the great areas of gumbo soil have been formed, and hence the one universal characteristic of gumbo is that it is gritless when in its primitive condition. The color may vary from gray to black, owing to the amount of organic matter which it contains, but this does not materially change its character. When wet it sticks and when dry it breaks up into cubes or granulates, whence comes the name "buckshot," which is often heard. A careful study of this subject will reveal the fact that there is a general rule or order to this formation which is quite natural and very interesting. Where perfect quiet prevails, a perfect, gritless gumbo is deposited. If a slight agitation is present very fine sand or grit will be deposited and, as we follow up the line of increasing agitation, the percentage of gumbo decreases and the percentage of grit and sand increases. Thus from the bottom of the lake to the mountain torrent every phase of separation exists and the product of each phase is positive and well defined. At the point of greatest agitation great bowlders are moved to a place of less agitation, then coarse gravel is dropped, next coarse sand, then finer silt, and lastly the finest falls on the bottom of the lake. Variation in the flood varies the deposit line; hence the lamination and overlapping of the different grades. Likewise there exists great variation even in a lake. Near the surface and the shore the winds produce violent wave action and only sand, pebbles, and such heavy particles can remain. As we pass in from the shore line a change in the character of the deposit takes place in rigid

obedience to the laws of gravity and the suspending power of water. Nowhere is this subject as plainly written or as richly illustrated as in the Middle West. It furnishes a key to the study of the glacial deposits and clearly indicates whether they projected themselves as icebergs into an inland sea or formed a highland morain and a river flowing therefrom.

This subject of sedimentation is not only exceedingly interesting, but forms a most instructive study for the road builder. Following the inverse order of formation, next to the gumbo are found the loam deposits. These vary from almost gritless to a sandy loam. Let us consider next the physical characteristics and behavior of this loam as it relates to the matter of road improvement.

SEDIMENTARY LOAM.

The sedimentary loams embrace every type between gumbo and clean sand. Here a most important manifestation presents itself—as the percentage of sand increases, the tendency to granulate or form "buckshot" decreases. This is an important physical fact for the road builder. Moreover, it is noticeable that, as the percentage of sand increases the sticky tendency manifested by buckshot decreases; in other words, as the properties of clay disappear the characteristics of sand rise into prominence. It is a characteristic of clay to crack when in the process of drying, owing to the unequal shrinkage, and likewise to expand when the water is restored. Sand has no such tendency, but rather contracts when water is added, by reason of the closer relations formed between the grains. These diametrically opposite manifestations should operate to neutralize each other and a point should be reached where the sand would be sufficient to prevent further contraction or expansion, or at least sufficient to prevent cracking to any appreciable extent. At the same time it should stop the tendency of the clay to stick, because in this respect the sand is also diametrically opposite to the clay. By a careful study of these various physical conditions and an observation of the effect of travel, a correct theory may be established. This theory is that there is a point between the gumbo limit on the one side and the clean sand on the other where the opposite characteristics of each are neutralized and the resulting composition is a better road material than either alone. Innumerable sections of sedimentary loam are naturally good and easily kept in excellent state with very little attention. This kind of road, which is one type of the sand-clay road, is very responsive to the drag and soon shows a perfect wearing surface, if the drainage is good.

This class of material covers also large areas in the Middle West, and a discussion of a method of constructing improved roads in this

area is of importance to many of the best farming sections of that territory. The presence of the many good sections of roads is a cause for encouragement. If it is possible, by natural processes, to bring the materials together in the proper proportions, a careful study of these proportions in any locality should lead to an artificial reproduction. This has been done many times and may be attempted with the utmost confidence of success. When the methods of constructing a sand-clay road and the principles involved are discussed, this type will be explained more fully.

SAND.

Next to the loam deposits, in the order of separation, is sand. Even when it is very fine, it may still be clean. When dry it is extremely mobile and drifts in the wind like snow. Indeed the effect of the wind is most marvelous; hills are piled up sometimes nearly a hundred feet high, only to be torn down and then piled up again. Deep basins are blown out, to be subsequently filled again. To the man or beast of burden that must cross this sand it is anything but play. Perhaps no known road is so dreadful as one of those deep, shifting, sand-hill roads of the Middle West. Fortunately, in most cases these sandy areas are covered with vegetation, which limits to a great extent the effect of the wind, gives permanency to the surface configuration, and saves the road from being inundated with drifting sand. As the sand becomes coarser it is less affected by the wind, but clean sand, whether fine or coarse, cuts deep and, even on a level a horse's feet sink into it at each step, thus greatly increasing labor; but if to this is added a grade of from 5 to 7 per cent, the difficulty is so great as to become an impassable barrier. It is needless, then, to say that the people of the sand hills are urgent in their appeal for better roads.

By far the greater part of this sand is quite fine and clean, like shore sand, but an occasional drift of coarse sand and gravel is found. This latter deposit deserves a careful search, for it is of great value in the improvement of the roads in the gumbo sections, as will be explained later on.

The sand hills are peculiar in their distribution. In some instances they are narrow strips along a river, while in others they are quite extensive and cover wide areas. Nor are the strips uniform in width or continuous on one side of a river. They may be on either side and may vary in width from a few hundred feet to several miles, but however wide or in what manner they may be located their characteristics never change—they make speed impossible and increase the labor necessary to move a load to more than six times that needed on a good road. The area covered by a heavy sand is great; conse-

quently the method of hardening it and improving the roads in it is one of the most important problems to be solved in connection with the movement for better roads in the Middle West. Every formation found in connection with the sands will therefore be considered.

GYPSUM.

Throughout a great portion of this territory abound deposits of gypsum, which vary from immense cliffs to thin strata (fig. 1). Occasionally there are secondary deposits in the form of pockets, banks, and wide level sections, but these are due in a large measure to comparatively recent erosion and sedimentation. The exposed cliffs and other outcroppings are often disintegrated by the action of the weather,

FIG. 1.—Gypsum pit, showing lamination.

and are quite chalk-like, but deeper down these deposits become tenacious and show a decided tendency to greater cementation when placed upon the road and subjected to travel.

This type marks the extreme of the gypsum deposit as far as hardness is concerned; and, while it would not be a first-class material for macadam, yet, because of its chert-like characteristics, it would make a good road when used in the same manner as a chert-gravel. This fact is apparent from the character of the road where it crosses such a formation. The extreme of worthlessness in this class is found in the chalk-like deposits, which have lost all binding power and readily pulverize and, when pulverized, never re-cement. This type makes an exceedingly poor road for the Middle West, because the deep dust formed on it is so readily blown away.

An occasional deposit of gypsum of recent formation is to be found in layers from an inch to a foot or more in thickness, alternating with sand and gravel. Such deposits are usually granular and not massive. They thereby show that they were of secondary formation and the result of violent erosion which tore them from the softer bed and tumbled them along in the course of the flowing stream to a place of less agitation, where the granulated layer is found in the sand and gravel deposits. This formation is readily distinguishable from the massive as well as from the gypsum clays. This observation is necessary in order to distinguish between a gypsum clay and a gypsum sand; the former is usually a good binder for sand, while the latter is not.

SHALES.

Besides the gypsum deposits, shale is another material worthy of notice in the construction of this kind of roads. This of itself is a poor road material, whether hard or soft. If soft, it quickly absorbs moisture and readily mucks up under travel; if hard, it is of uneven texture and wears rapidly into an uneven road surface. The addition of sand, however, will in a measure improve soft shale by giving it body, but, because of its poor binding qualities and the ease with which the rains wash it out from the sand and leave the sand loose and unsupported by a binder, it must be classed as a poor road material and used only when no other is available.

There is a deposit of red shale-like clay of extensive and massive proportions in southwestern Kansas and Oklahoma. This material noticeably differs from the true shale in the matter of binding power. It has quite a good degree of tenacity and, when used as clay for sand-clay road construction, it gives fair results. This formation grades from a massive red clay to a red sandstone. Its value as a road material decreases as it approaches sandstone. The best deposits of this material usually occur in secondary deposits at the foot of the hills in the river valleys. They are the product of recent erosion and deposit, which have separated the clay from the sand and carried the clay farther on, where it is deposited in a purer state, so that it is a better binding clay for sharp sand. Such a deposit along the Cimarron River has been used at Englewood and Ashland, Kans., with very satisfactory results.

Besides the foregoing formations and deposits there is a very peculiar deposit south of Sargent, Nebr. The same formation appears at other places in the Middle West. It is not laminated or stratified, but massive and quite regular in texture. It is gritless and evidently a sedimentary deposit, but its composition has not yet been determined. It appears to be composed of chalk and kaolin, although the mixture, if any, is perfect, and beds 20 feet and more in thickness

show no variation. Its color is an ashen gray, and when deeply cut by erosion it stands in a vertical wall. It shows little tendency to crack on drying, which is an indication of small shrinkage. It was observed that this material behaves very well when placed upon the road; it packs smooth and appears to wear well, showing little tendency to failure, either from dust or mud, although it is believed that an addition of sharp sand would materially improve it during periods of long rain.

RIVER SANDS.

A very important feature of this territory for the road builder to consider is the character of the sands carried by the larger rivers, such as the Missouri, the Loup, the Platte, the Arkansas, the Cimarron, and others rising among the sand hills or farther up the slopes of the Rockies. In many localities immense deposits of very coarse, sharp sand may be found and these are valuable to the builder of sand-clay roads. Eventually their immense value will be appreciated and utilized to harden the plastic soils found farther east, whither these rivers bear their sand.

RIVER SILT IN IRRIGATION LAKES.

It might not be amiss to call attention to a controllable and probable source of material for making the surface of roads hard in the sandy lands in the irrigation belt. All the irrigation waters carry a large quantity of sediment which they deposit in the basins and lakes formed for the storage of river water. This sediment is practically the same material as the gumbo found in the valleys farther down, and may be used in the same way for the purpose of improving the roads. The road at Dodge City, Kans., was built of this material, and so far only good results are reported. Many miles of roads might possibly be constructed in this way by systematically gathering the sediment at a convenient point for use on the roads.

CLIMATE.

The climate is a factor of importance for the road builder to consider in the Middle West. In the eastern sections, where the soil is plastic, the rains are most abundant, while in the western sand hills the climate is semiarid and quite strong south winds prevail. These conditions introduce an important matter for consideration. Sand roads are best when wet, and clay roads when dry, but climatic conditions operate adversely and must be taken into consideration seriously. The rains make the eastern roads muddy, while dry weather makes of the western roads deep shifting sand. The suggestion offered by this natural condition is to add sand to the

eastern clays and clay to the western sands in order to bring about, between the soil and the climate, the balance necessary for the betterment of the roads. Additional encouragement is afforded by the natural distribution of the material, which in most cases is abundantly provided for all needs.

DRAINAGE.

There is another important matter to be considered on account of climate. In the eastern portion, where rains are abundant, the question of drainage is very important, and, moreover, a greater percentage of sand (65 to 85 per cent) must be used, while in the West, in the semiarid sand-hill section, the reverse proportion is not only permissible but often necessary. In the East the road must meet, as its supreme test, continued wet weather, while in the West continued drought furnishes a maximum strain on the binding power of the clay. In the East the road is likely to fail by reason of mud holes and washes; in the West it must resist pulverizing and blowing away as dust. Between these two extremes lie all the possible methods of sand-clay road construction. Upon the judgment of the supervisor, therefore, depends the character of the work to be done. He should know how to select the best available clay for the conditions to be met, and likewise how to select the sand and incorporate it with the clay so as to obtain the best possible results.

CONSTRUCTION OF A SAND-CLAY ROAD.

IN THE GUMBO OR PLASTIC SOIL SECTIONS.

Here the one primary consideration is the selection of sand. Since in many cases it must be hauled quite a distance, great care should be exercised in the selection in order to procure the sharpest and coarsest sand possible. After the sand is selected it is a good plan to haul it, in advance, alongside the road which is to be improved. When the road softens a quantity of sand should be spread broadcast over the traveled roadway for the desired width—about 14 to 18 feet—until the softened clay surface of the road is saturated with the sand. In this way the advantages of hauling the sand on a firm, dry clay road are obtained and it is ready for use when the road is softened by rain and slightly cut by travel. The amount of sand to be used is determined by the character of the road. If the road is taken before it is deeply cut by travel less sand will be required to give it a hard surface than would be the case were it delayed until deeply cut and full of mud holes. No ultimate harm would come from allowing it to become deep mud, but an unnecessarily large quantity of sand would be required to effect a remedy and

would entail needless expense for surface material. For the first application of sand from 5 to 8 inches should be sufficient to give a hard surface to almost any well-drained road, however plastic it may be. If, however, the surface is deeply cut, it may require twice as much sand to form a good road. This caution is given for the sake of economy both in hauling the sand to the road and in using it afterwards, rather than in the final effect to be obtained. However deep the mud hole may be, sand can fill it and make it permanently firm for travel. Although this is effective in improving the worst mud, still it is expensive and great economy will result by applying sand, when the clay is softened, to a depth of about 3 or 4 inches. An excellent state of preparation can be had by driving a herd of cattle over the road when wet and at the same time adding the sand. By this simple method a thorough mixture of the surface clay and sand is formed, and, as it dries somewhat, a split-log drag may be used to produce the crown and maintain it until the road is hard and smooth under travel. Should any place in the road fail and become muddy, more sand must be added each time such a failure is noticed. If this direction is followed the result will be quite satisfactory, notwithstanding its simplicity. In the absence of the herd of cattle an excellent surface condition preparatory for the sand can be obtained by using a disk or tooth harrow to loosen the surface of the clay.

While it has not been specifically stated, it is assumed that the road to be improved has been properly laid out, drained, and graded to the desired crown before being prepared for the application of the sand. The subsequent dragging is merely to even inequalities while the road is settling under traffic. If a coarse sand is not available any clean sand available may be used. It is often a matter of using, not what one judges best, but such as can be had within the means of the supervisor. Any sand will improve a clay road.

Simple as this method is, it is nevertheless applicable to the whole plastic clay belt. Roads which are now almost impassable in rainy weather, as were nearly all the roads in eastern Kansas and Nebraska in June, 1908, may be rendered practically firm for all travel and even well suited for automobiles. The depth of the sand-clay mixture must be in proportion to the burden of travel. If the road is to withstand very heavy travel and extreme weather conditions, a deep sand-clay composition will be necessary, and there should be only clay enough in the composition to fill the voids in the sand and to act as a binder.[a]

[a] For a further discussion of this subject, reference is made to Farmers' Bulletin No. 311, entitled "Sand-clay and Burnt-clay Roads."

From a careful study of conditions it is believed that the application of sand, as above described, will prove a practical solution of the road problem for the plastic clay soils. Where sand is not available locally it may be transported by rail, delivered in chutes, loaded therefrom by gravity into wagons, and hauled to the roadside for less cost than macadam, and in most cases it will prove equal, if not superior, to the more expensive macadam road. But no half-hearted effort should be attempted. A steam shovel should be used to load cars of the ballast type, and they should be unloaded into chutes by gravity at the desired station. The sand may then be dropped into dump wagons, hauled to the place of use, and dropped in sufficient quantity in regular order along the road to be improved. This is a practical and economical method by which much may be accomplished.

IMPROVING LOAM AND ALKALI SOIL ROADS.

Usually the loams have a very good degree of fine sand intermixed, and careful attention to drainage and the crown often proves sufficient to make a good road, if dragged occasionally when wet. Especial care should be given to drainage if the body of the road is to be of loam. The traveled roadway should be at least 18 inches above the level of ditch water. It is also important to provide against either of two extremes—water standing in the side ditch or flowing too great a distance down a slope in the ditch. Both are disastrous to the road. The one saturates and softens the road bed, causing it to fail, and the other forms a gully of the ditch and washes the road away. A good maxim is "Ditch the side ditches." This is of great importance and well worth remembering. It not only applies to a loam soil, but to all kinds of soils and conditions with one exception, viz, where the sand subsoil is several feet deep and sufficiently porous to absorb any rainfall no side ditch is required and no attention need be given to the drainage of the road beyond crowning the sand-clay surface. Such deep sand is found only in the sand hills. In all cases where the sand is under 10 inches deep or underlaid with clay or hardpan of any kind, well-constructed side ditches must be provided.

All forms of hard roads should have a good crown, varying from side to center. The slope of the crown should be greatest at the sides and flattened as it approaches the center. Only a sand road requires no crown at all. Where nothing but deep sand prevails, the surface should be concave for the purpose of conserving, as far as possible, the moisture. Sand alone is improved by water.

The same directions given for loam constructions may be followed in the case of alkali soil. A difference, however, usually exists in the case of alkali soils. They are more sticky and are flat and low.

The one thing, therefore, of prime importance is drainage. To effect this it is often necessary to build up the road above the adjacent land. It is more important usually to build up an alkali soil road than one of loam soil because the alkali is more liable to failure where imperfect drainage exists. For this reason it is important that the road should have a width of not less than 30 feet, in order to give permanency and utility to the traveled way, and a sodded shoulder on either side to prevent washing.

If the construction of the road in alkali soil is followed with systematic and faithful dragging a very satisfactory road will be obtained. Should a muck-like condition continue after each rain and the road fail to harden satisfactorily it should be treated with an application of sand as outlined for gumbo.

USE OF SAND-CLAY ON SAND-HILL ROADS.

Perhaps the sandy roads in the sand-hill regions of the Middle West are the worst stretches of road to be found in this country. They often lie as impassable barriers between fertile lands and vary from a few hundred yards to several miles in width. To haul a load across a mile of such sand costs ten times as much as on a hard, smooth surface. It is, then, a most vital matter for the people living in the vicinity and having occasion to use these roads to build hard-surface roads through the sand. Many experiments have been made with varying results, but so far it appears that the sand-clay road is the practical road, and particularly so in the semiarid regions. Indeed, it appears that here the sand-clay road is capable of yielding the most satisfactory results both as to service and durability. Because of the dryness of the climate the clay rarely becomes oversaturated; on the other hand, however, the sand always contains enough moisture to keep the base of the clay in a state of sufficient moisture to prevent cracking at the bottom of the clay. This percentage of moisture, while small, is sufficient to strengthen the road surface greatly; but while this factor is important, there is another equally as advantageous in the porous character of the sandy base. It allows the excess of moisture to percolate, however hard it rains; there is therefore an interesting principle disclosed in this deep sand. It may be compared to a governor regulating the moisture admitted to the clay from beneath. According to this principle, one would expect to find the best sand-clay roads where the sand is deepest, and such is the case. The sand furnishes a perfect underdrainage and yet capillarity supplies the right amount of moisture to maintain the bond in the clay and prevent its becoming thoroughly dry, in which case it would crumble to dust and be dissipated either by the wind or in the deep sand. Again, this principle makes it possible and even practicable to have a satisfactory clay

road on deep sand when the clay is largely in excess. Such a road would utterly fail on a clay foundation. Here, again, this principle is of great advantage, because the clay can be left in excess in the body and sand added to the surface only after the clay has been applied.

The importance of a careful location is not always as seriously considered as the nature of the case justifies. It too often happens that an effort is made to follow the section line. Normally, in lands valuable for cultivation, this may be justified, but in grazing lands, where the roads should be located with a view to an economic maintenance and an economic haul over the road, both of which require low grades, the case is not the same. Again, to build a sand-clay road over the top of a sand hill is to invite the winds to destroy it. It is therefore of importance that the location be as free from grades as possible and protected from drift sand or "blows."

After the location has been selected a roadway not less than 30 feet wide should be laid out. All inequalities should be graded out so as to give a smooth road with a uniform cross section. When this has been done stakes should be set for the center line of the road, and for this purpose plaster laths serve excellently. With a turning plow a furrow should be run up one side of the row of stakes and back on the other side, throwing the dirt toward the stakes. In this way a ridge is made exactly in the center of the road. Then a roadbed should be thrown up to the width to be clayed by backfurrowing to this ridge. A drag or harrow should be used to smooth this bed and the crown should be carefully made to conform to the proposed finished road. A good practical width for this bed is 14 feet. After the central section has thus been prepared and smoothed with a harrow or drag the shoulders should be backfurrowed on both sides of this clay bed with the turning plow. To do this the plow should be set so that it will discharge the material in a ridge just outside of the last furrow made in forming the bed. Thus by several rounds with the plow the shoulder is raised sufficiently to form a protection to the sides of the clay when placed in the prepared bed. Usually five such furrows on either side complete a 30-foot road to the ditch line. When this is done the sand bed is ready for the clay to be hauled upon it.

If in the foregoing operation any stakes have been misplaced from the center they should now be restored in order to maintain the center line of the road definitely. The first six or eight loads of clay should be dropped exactly in line with these center stakes. The next loads are dropped on one side of the center loads, inside of the shoulder, but only about half as many should be dropped on the side as were dropped in the center. Clay should then be dropped on the other side in the same manner. This work should be done in such a way that the center line is some 50 feet

in advance of one side line and the first side line about the same distance in advance of the other—an arrangement by which three loads can be unloaded at once. With this plan the teams will not be blocked in hauling, and, furthermore, by keeping the center line well in advance of the sides it is an easy matter to keep the road true and even.

After 200 linear yards of the road have been covered the clay should be spread. It is important not to begin to spread the material immediately after being dropped upon the road. The reason for this will appear later. Nothing is better for the purpose of spreading the clay than a two-horse two-wheel grader. The spreading is begun by pushing the side loads toward the center to fill in the space between the center and the side loads which has already been rolled by the wheels of the loaded wagons. After this has been done the hauling should be continued until the material has been thoroughly packed by the wheels of the loaded wagons passing over it. The center may then be brought toward the sides with the grader and the entire road smoothed. Travel may now be freely allowed on any part of the surface of the road. If the loads of clay average 1 cubic yard each they should be dropped touching each other in the row, but if less than 1 cubic yard they should be slightly lapped. The person in charge of this part of the work should exercise his judgment in the matter of dropping the loads according to the size in order to secure the desired depth of clay, which should not be less than 6 inches, while it may be as much as 12 inches when very heavy loads, such as traction engines, are to pass over it.

The side loads should be pulled toward the center first for the purpose of preserving the crown and keeping the material well toward the center, since it is easier to cut down the crown later, if too high, than to build it up. This is also important for the reason that the teaming must be depended on to do the rolling, since it is not expected that a roller will be used. Moreover, if the center is left undisturbed the teams will naturally follow on each side of the crown and, in consequence, the wheels of the loaded wagons will roll in the proper place to give the greatest rolling effect to that part of the road which will afterwards bear the heaviest burden of travel, leaving the material of the center loads in condition to be handled by the grader when the center is to be dressed. Then, last of all, the surface is finished with the grader. Especial care has been taken to make this detail clear, for upon careful attention to it depends the smoothness of the road when completed. Perhaps no part of the construction is as important as the matter of providing an even texture and a surface in the outset free from small depressions. For the semiarid sand hills this is especially important, because it is not the purpose ever to break the bed of clay up entirely in the applica-

tion of the sand. If by neglect or other cause the clay has been dropped improperly, causing a thin place, the necessary repair should be made at once and all the material should receive the same rolling in construction. It is quite important in the semiarid territory to have the clay fairly well compacted before the sand is added, and to add sand only on top of the clay, in the manner described above for sticky soils. Indeed, the construction is identically the same, after the clay has been placed on the deep sand, as that described for gumbo or any other clay district, with this exception—the sand, in the case of the sand-hill road, will not have to enter as deeply into the clay or form as large a percentage in the composition, except for the upper inch or two of the surface. The greater part of the clay remains undisturbed as when placed on the sand. It is expedient and proper, however, to have at all times a coating of sand on the road. After the road has been properly smoothed the grader may be reversed with good effect to bring a covering of sand from the sides of the road, which have been previously plowed up for the shoulders during the preparation of the roadbed. It may happen that by hauling over it the clay will be pulverized to such an extent that an inch or more of dust may form on the surface. In this case the fine, mechanical separation can be used to advantage by incorporating an abundance of sand with the dust. Sufficient sand, fully twice as much as the amount of dust, if gumbo, should be added and thoroughly mixed by means of a tooth harrow. When the rains come only mucking and settling remain to complete the composition.

There is one important thing to avoid in this dry climate. The clay should not be disturbed deeper than there is moisture to reunite it at the time that sand is added. The road should be built of clay, covered with sand, and left to the rains to soften the clay so that it can absorb the sand. The clay should never be pierced to the sand base, for the reason that, if it should be continuously dry for a long time the loose sand would work up from below and cause sandy pockets and sandy places in the road, not unlike mud holes in a clay road in effect. This is quite important in drift and very fine sand.

After the clay has been placed upon the road, sanded, and treated as above described, the turning plow should again be used to build up the sandy shoulders until nearly level with the clayed part. In this way a trap will be set for all the clay that blows or washes to the sides. This is not only permissible in a sand-clay road, with deep sand, but desirable. It is not so in a road entirely of clay, and this distinction should be noted. Another reason for lifting the sand shoulders so high is to conserve moisture, the opposite of what is necessary in the case of sand-clay construction on a clay subsoil. It must be carefully observed that this last suggestion applies to deep sand only and never to shallow sand, where the rain is not at

once absorbed. Every effort should be made to conserve moisture in deep sand and a dry climate, because the moisture prevents dust and the consequent blowing away of the road. It is therefore a matter of necessity, if the greatest success is to be attained, that these local conditions be carefully considered in every detail of the construction. The building up of the shoulders is of advantage to the road when it is to be dragged, because then it is an easy matter to get from the shoulders the sand needed on the softened sand-clay roadway.

While it is customary to use the sand along the road, yet if it is very fine and there is coarse sand near by it will often pay to haul a slight covering of the coarse quality upon the clay. This is particularly advantageous where the winds are very strong, because the coarse sand is far more resistant to the winds and far less disposed to break up the clay bond. It acts in the same way that coarse sand does with cement. The shoulders should be plowed out to the ditch line and, as far as possible, vegetation of some kind should be encouraged to grow on the sandy berm. All these points should be observed to prevent the sand from blowing away and leaving the sand-clay road unprotected. If much rain should come and the clay should soften as much sand should be added as the softened clay will mix with well and the sanding should be followed with a drag until the road is again dry and firm.

The maintenance of the road is of the utmost importance for one or two years after construction. Proper care at the right time often saves a whole road from failure. There is nothing permanent about a road except its location, and nowhere is that saying truer than in the sand hills. Even the location is often in jeopardy.

Nothing has been said so far about the choice of the material to be used as the clay part of the sand-clay road in the sand hills. The choice is usually limited to gypsum, alkali soil, or gumbo. Sometimes only one is available, but when more than one can be had it is important to know how to select the best. It has been pointed out that gypsum varies from a chalklike, nonbinding, easily pulverized mass to a composition of semiplastic gypsum and clay, which, under travel, hardens on the road like cement. This latter is quite useful as a road material, while the former is practically worthless, because it lacks binding power. The binding power is one of the properties to be sought for most carefully. If the material packs readily and pulverizes slowly when dry, or softens slowly when wet, it may be safely accepted as a suitable material for making the surface of a sand road hard. This characteristic alone can be relied upon. Color has little or no significance as to its value.

The alkali soils are more or less variable in composition, usually containing a certain proportion of sand, silt, clay, and organic

matter. In some respects they are very much like the loams, but they contain varying percentages of different soluble salts. As a rule, very little sand need be added to an alkali hard surface material. The best results come from spreading it on rather heavily and dragging thoroughly afterwards. Gumbo is one of the materials sometimes met with and, if it is free from grit, a large amount of sand will have to be added. This material has the peculiarity of cracking in every direction when it thoroughly dries out. This makes it necessary to add more sand after each rain and also when the gumbo dries and cracks. These cracks should be filled with sand as often as they appear and this should be continued until sufficient sand is incorporated to stop the cracking completely. This characteristic of the gumbo of splitting up into thousands of little pieces is of immense advantage for introducing sand, but it is of serious consequence in periods of extended drought, because it may cause the complete failure of the road before the necessary sand can be incorporated with the gumbo. If once the sand and gumbo are mixed and compacted by travel, little is to be feared thereafter. It is clear, therefore, that, when gumbo is used, it is important to utilize to the fullest extent every rain, in order to puddle the surface and to do everything possible to conserve the moisture in the gumbo by keeping the sand shoulders high, even above the level of the clay portion of the road. It is better to do this, for the additional reason that it will help to keep the rain water on the gumbo and soften it to a greater depth, and thereby allow a more thorough intermixing of the sand with the gumbo. It should always be kept covered with a little sand. Whatever the variety of gumbo, whether from a lake bottom, the overflow of a river, or an irrigation ditch, its characteristics are practically the same, and it will be valuable as a road material in proportion to its binding power and ability to resist washing or pulverizing and consequent blowing away.

An occasional deposit of pipe clay may be encountered in certain sandy sections, as at Hutchinson, Kans. The treatment of this material differs somewhat from that given to the other types of clay mentioned above. It should be placed upon the road and covered with sand, as described for gumbo, but the difference consists chiefly in the difficulty experienced in the endeavor to incorporate sand with clay. It has a remarkable tendency to remain in lumps and to resist all efforts to pulverize it or to puddle sand into it. It usually requires a great deal of time and labor to mix sand with pipe clay to the proper point of combination. A dozen herds of cattle driven over the road are needed to effect a proper combination; perhaps a thousand sheep would effect the proper puddling of pipe clay more easily. Aside from this difference there is one other point well

worth noting regarding pipe clay. It shows this tendency to form lumps when dug or plowed up in the pit. If these lumps are not broken before they are dropped on the road it is very difficult to produce a proper clay bed with an even and uniform thickness overlaying the sand. Eventually these lumps will cause inequalities in the surface. Considerable care should be exercised to have the pipe clay as finely divided as possible when placed on the road, so that it can be spread evenly.

It should not be forgotten that sand is needed in considerable quantities for pipe clay and that the proper time to add it is when the clay is in a muddy state and being puddled.

FIG. 2.—Section of road covered with sand-oil. To be replaced by gypsum.

SAND-OIL COVERING FOR A SAND-CLAY ROAD.

At Garden City, Kans., oil was tried on a section of a very sandy road, and it had been planned to parallel the oil with gypsum sand-clay. The suggestion was made that this oiled sand might with advantage be spread evenly over the finished part of gypsum sand-clay. So far this is an untried experiment and results are not known, but the object is to provide a dustless covering to the gypsum road, resisting both wind and rain. It might possibly have the additional effect of providing a cushionlike protection to the hard surface below. Thus the three things which might result in the betterment of the road are a dust preventive, a wind and water resistant, and a cushionlike effect to relieve the impact of travel and thereby prolong the life of the road. At Garden City, Kans., the sand is already saturated with the oil, and the experiment may be tried with little or no cost. (Figs. 2 and 3.)

It is well known that the successful use of oil in road building depends largely upon the nature of the materials used. Natural oils vary widely in their characteristics and the same may be said in regard to tars. The possible use of bituminous materials in connection with sand-clay construction must be worked out experimentally before definite instruction in regard to it can be given.

EXPERIMENTS IN THE MIDDLE WEST.

We may now proceed to give concrete examples of work actually done and a description of the methods pursued in construction. To this end a description will be given of the roads at Garden City, Dodge City, Bucklin, and Ford, Kans., with the peculiarities of each

FIG. 3.—Gypsum road winding through sand hills.

case and the methods employed, together with results of inspection of these roads after a year's use. In addition to this a few views of these roads will be given as they appeared one year after construction.

Garden City, Kans.—The road selected at Garden City was a part of the Santa Fe road leading south from the station. The work was begun at the foot of the sand hills on the southern side of the Arkansas River. From the starting point the grade rose about 6 per cent, or perhaps a little more, for a distance of about 500 feet, and then ran level for some distance. To give this heavy grade a hard surface was of the utmost importance, because it was impossible with the funds available to reduce the grade, and a change of location was out of the question.

About 300 yards east of the road a deposit of gypsum clay was found and uncovered, and from this pit were taken 68 cubic yards. It was

abandoned because of the heavy sand between the pit and the road, and for the additional reason that the sand could be stripped from a gypsum deposit near the road and material obtained there more cheaply. This pit was immediately on the roadside and promised sufficient material for the completion of the contemplated section. It proved a wise decision to use this pit, for it was found that it improved in quality as the excavation became deeper. It showed greater tenacity and bonded much better than that from the first pit.

Because the road was practically level in the cross section, no preparation at all was made in the subgrade, except to stake out the center and side lines in order to guide the teamsters in hauling. The proposed width was 12 feet of clay, and for this width a full load was dropped on either side of the center and a half load in the middle between the side loads. The whole was spread as evenly as possible by hand and hauled over as fast at it was spread. All weak and defective places were reenforced as soon as they appeared, and the proper crown was formed as the work proceeded. An effort was made to add the clay to a depth of about 9 inches and a width of 12 feet, but, since there were no shoulders and since 12 feet made too narrow a road, the material was allowed to spread to 14 feet, so that the clay tapered off 12 inches on the sides. In this simple manner the entire section of 765 feet was constructed. The operation so far consisted simply in hauling gypsum clay and spreading it evenly on the road in a straight line and to an even depth and width. During this time the public was allowed undisturbed use of the road, and was even invited to use it for the purpose of packing the surface.

After this packing was accomplished, fortunately a very heavy rain fell and effectually saturated the clay and the sand beneath it. The road was then harrowed with a toothed harrow to break all the lumps on the surface and to prepare it for the sand which was next to be added. For the sanding a heavy two-horse turning plow was used, and the sand was backfurrowed up to the clay on both sides. A common drag was then used to pull the sand upon the clay and the harrow was used to mix them. Finally, after several draggings and harrowings, the road was left for travel. After one year the same road was visited and was found to be as firm and hard as macadam. The people are so well pleased that they have continued the construction entirely across the sand southward for a distance of 7 miles.

Dodge City, Kans.—At Dodge City a part of the Minneola road was selected. This road, like the one at Garden City, was south of the Arkansas River in the sand hills. The sand here made so serious an obstacle that the road was little used, and travelers preferred to go a mile or more out of the way to avoid it. A search for clay revealed,

near the middle of the section to be improved, a deposit of sediment from an irrigation ditch. This deposit was about 18 or 20 inches thick and extended over an area of 3 or 4 acres. It was decided to use this material, because it was the only thing at hand. Accordingly it was plowed as deep as two horses could pull the plow. It was then found to be dry enough to granulate perfectly, and consequently it was in fine condition for loading into wagons and spreading on the road. The loading was done by hand and common farm wagons were used. For the wagon boxes the material used was 2 by 4 inch scantling for the bottom and $1\frac{1}{2}$ by 10 inch planks for the sides; all were 11 feet long. Two by 6 inch scantling is perhaps better for the bottoms than the dimensions given above, because this size requires less handling.

The preparation of the subgrade was made in advance of the clay hauling and was done in the following manner: Unlike the work at Garden City, a subgrade of definite form and width was prepared. The center line was first laid out and backfurrowed in the manner described on page 18. The specifications given there were also followed in dropping and spreading the clay. During the construction there was no rain and dust formed an inch or more deep. Into this a large amount of sand was harrowed, and the road was finally covered with a layer of sand in preparation for rain. When the rain came the sand was completely absorbed by the clay and an additional application was required to overcome the tendency to stick. This was added after each rain and worked in as opportunity allowed. The clay also cracked quite deeply when it dried out, and to meet this contingency more sand was added and worked into the cracks with the drag. Shoulders were plowed up on either side in the same manner as at Garden City, and sand was pulled upon the clay with a two-horse grader. A large grader was also used to dress the road and to pull sand upon the clay; but still better was the drag scraper for sanding the clay. This method proved the most satisfactory of all. By this means all high places on the roadside were graded, and the sand thus obtained was used to cover the clay. The use of the drag scraper was found far more expeditious than hand work. No roller was used on this work, but the travel was so distributed as to roll every portion of the road evenly.

One year after the road was constructed the accompanying photograph (fig. 4) was taken. The road has shown its ability to withstand travel and has converted what was formerly a little-used road into one of the most heavily traveled roads leading into Dodge City. It has clearly demonstrated the value of a good road. Formerly the farmers who had to travel along it were seriously considering the advisability of selling their farms and going where the roads were better. Now they easily haul 60 bushels of wheat with a two-horse team.

In fact, the usual benefits which are brought about by good roads were quick to follow the successful outcome of this work inaugurated by the Office of Public Roads.

Bucklin, Kans.—Simultaneously with the work at Dodge City, a section of an experimental road, 5 miles north of Bucklin, was constructed. The section laid out was supposed to be a mile and a half long, and the plan of construction was identical with the work at Dodge City. For the material for giving a hard surface there was no artificial lake of sedimentary clay, as at Dodge City. At first it was thought that it would be necessary to haul all the material from the river valley up the hill, but the inspection of a basin on the summit of the hill, near the south end of the section, indicated the possibility of a fairly good material, which, if it should have the necessary binding

FIG. 4.—Object-lesson road at Dodge City, Kans.

power, might mean a great saving in the cost of construction. From this point a haul downhill could be obtained, and from the importance of this matter it was deemed worthy of trial. Some of this material was plowed up and put on the road. This surface material at first showed a tendency to blister, and its binding power seemed very slight, but as the depth of the pit increased a decided improvement was apparent and excellent material was found beneath the surface soil. A great saving in the cost of construction, well worth the experiment, was thus accomplished.

At the south end of the road, 3,276 feet of road were clayed from the clay pit described above. This was a haul downhill, and the material was spread on heavier than is usually done because it seemed likely that it would not support the travel. The work was then stopped

at the south end and begun at the north end of the section. At this end 995 feet were clayed and, when a bed for clay in the intervening space, which was about 2,500 feet long, had been prepared, it was left for the community to clay according to the plan given them. This was done by them, and one year after the work was done the accompanying photograph (fig. 5), showing this road, was taken. It will be observed that, while it is not smooth, it is not cut into ruts, and only the surface has picked up. The night before the photograph was taken it had rained quite hard and had softened the surface sufficiently to cause it to pick up when travel passed over it. This indicated an insufficiency of sand on the surface and more had to be added to prevent this stickiness. The remedy in such cases is to cover the surface with sufficient sand to overcome this tendency.

FIG. 5.—Object-lesson road at Bucklin, Kans.

Ford, Kans.—The construction at this place was quite peculiar, because of the weather conditions. During the night the road would freeze hard, and, in order to take advantage of this condition, the gumbo-clay found in the river valley was plowed up in the afternoon when it had thawed out. The next morning the clay plowed the previous afternoon would be in frozen lumps as hard as stone. The men used gloves and threw these frozen lumps into the wagon by hand, as they would have done stones. In this rough state it was hauled upon the road and spread as well as possible. It was impossible to give a surface to the road until it had thawed in the afternoon. Then it was smoothed to some extent and the clay was covered with sharp sand 3 inches deep. Certainly no more crude form of construction could have been followed, but conditions were such as to prevent the use of any other method. This section was only a short approach

to a bridge. One year after this work was done the accompanying photograph (fig. 6) was taken, and, while the road was quite wet, still it shows from the tracks that the mud is not more than an inch deep and needs only a little more sand to overcome the excess of clay. This example shows how simple is the construction, and yet how effective, when clay is used for hardening the sand. The approach was a heavy sand bar, and had to be raised with sand 2 feet or more in places in order to make the grade easy.

These four experimental roads were constructed with local material and local conditions were met at the least possible cost. It is believed that a careful study of local conditions in any community will reveal many possibilities for improving the roads at a comparatively small cost. To aid in this study this article has been written,

FIG. 6.—Object-lesson road at Ford, Kans.

and it is hoped that a lively interest may be created in this work, and that the suggestions herein contained may be productive of much good in the great Middle West.

Where work of this kind is undertaken it may be well to make several experiments and tests and to note the difference in the results. In all forms of sand-clay construction the process requires the final mixing to be in the wet state, as otherwise there can be no bond. It is also of the utmost importance to use the drag frequently on the road during the first year, and as often as any part shows a tendency to stick or pick up it should have a surface coating of sand to prevent the clay from being carried off. It is necessary to study the needs of the road by actual observation rather than to endeavor to learn them from printed rules. Local conditions must be studied and overcome on their own ground.

SUMMARY OF DATA REGARDING CONSTRUCTION AND COST.

The following is a summarized statement of the work on the four roads just described and the cost of the different operations:

Garden City, Kans., Santa Fe road; date of construction, October 12 to 20, 1908.

Dimensions of road:		
Length of road	feet	765
Width of road, including ditches	do	30
Width of part clayed	do	12
Depth of clay	inches	9
Work of construction:		
Clay hauled	cubic yards	256
Surface clayed	square yards	1,020
Cost of construction:		
Stripping clay in pit		$7.17
Plowing up clay in pit		10.50
Loading clay by hand into wagons		33.00
Hauling clay to road		39.50
Spreading clay on road		10.00
Sanding, harrowing, and finishing road		2.33
Total		102.50
Cost of clay on road per cubic yard		.40
Cost per square yard of part clayed		.10
Rate per mile		707.45

Dodge City, Kans., Minneola road; date of construction, October 22 to December 10, 1908.

Dimensions of road:		
Length of road	feet	9,750
Width of road, including ditches	do	30
Width of clay	do	14
Depth of clay and sand composition	inches	11
Work of construction:		
Earth excavated	cubic yards	2,539
Clay hauled	do	3,703
Surface clayed	square yards	15,167
Cost of construction:		
Foreman for work		$51.50
Filling from barrow pit		9.00
Excavation (2,539 square yards)		387.69
Shaping subgrade (15,167 square yards)		70.00
Plowing up clay		54.875
Loading clay by hand		470.00
Hauling clay to road		608.38
Spreading clay on road		93.00
Harrowing and mixing clay and sand		6.00
Sanding road and building shoulders		107.685
Dressing road with grader		27.00
Work on bridge, timber, etc		59.53
Repairs, water boy, and sundries		3.75
Livery for experts		49.00
Miscellaneous		100.00
Total		2,097.41
Cost of road per square yard of clay		.138
Rate per mile		1,135.83

Bucklin, Kans., Spearville road; date of construction, November 21 to December 24, 1908.

Dimensions of road:	
Length of road laid off . . . feet . .	8,121
Width of road, including ditches . . . do	30
Width of road clayed . . . do	14
Length of road clayed . . . do	4,271
Depth of clay . . . inches . .	12
Work of construction:	
Earth excavated . . . cubic yards . .	1,584
Clay hauled . . . do	1,883
Surface clayed . . . square yards . .	6,644
Cost of construction:	
Foreman for work	$50.00
Excavation	224.07
Shaping subgrade for clay	32.37
Plowing up clay in pit	16.75
Loading clay into wagons	235.75
Hauling clay to road	304.875
Spreading clay on road	44.625
Repairs, etc	5.67
Livery for experts	35.25
Miscellaneous	9.00
Total	958.36
Cost of road per square yard of clay	.14
Rate per mile	1,183.64

Ford, Kans., Spearville road; date of construction, December 17 to 21, 1908.

Dimensions of road:	
Length of road laid off . . . feet . .	350
Width of road . . . do	30
Width of road clayed . . . do	16
Depth of clay . . . inches . .	13
Work of construction:	
Filling in and widening road . . . cubic yards . .	250
Clay hauled . . . do	179
Surface clayed . . . square yards . .	622
Cost of construction:	
Filling up and widening road	$17.25
Plowing and loading clay	10.50
Hauling clay	60.00
Spreading clay	8.00
Sanding clay	8.00
Dressing road with grader	.50
Total	104.25

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United States Department of Agriculture,

OFFICE OF PUBLIC ROADS—Circular No. 92.

LOGAN WALLER PAGE, Director.

PROGRESS REPORTS OF EXPERIMENTS IN DUST PREVENTION AND ROAD PRESERVATION.

INTRODUCTION.

A number of experiments in dust prevention and road preservation were conducted by the Office of Public Roads during the summer of 1909. It is the purpose of this circular to describe these experiments and to report the results obtained from experiments conducted along similar lines in previous years. Descriptions of these earlier experiments have already been published in Circulars 47, 89, and 90. The experiments conducted at Washington, D. C., Youngstown, Ohio, and Ithaca, N. Y., during the past summer will be described first.

EXPERIMENTS AT WASHINGTON, D. C. (1909).

WASTE SULPHITE LIQUORS.

Experiment No. 1.—Special Preparation.

In this experiment a concentrated waste sulphite liquor preparation was employed in the surface treatment of a macadam driveway for the purpose of determining its road-binding and dust-laying properties. The road selected for treatment is located in the Agricultural Department grounds, Washington, D. C., and connects Thirteenth and Fourteenth streets. It is built of trap rock with a soft limestone binder and, although subjected to only a moderate amount of light traffic, becomes quite dusty in dry weather.

The preparation was furnished free of charge by the manufacturers in 60-gallon barrels. It proved to be a dense sticky liquid, miscible with water, and having a specific gravity of from 1.267 to 1.270 at

25° C. Its binding value is dependent upon the presence of so-called calcium-magnesium-ligno-sulphonate, which is produced in the manufacture of wood-pulp according to the sulphite process.

Application was made by means of an ordinary 300-gallon sprinkling cart, and a mixture of equal parts of the preparation and water employed. The roadway was sprinkled three times with this mixture at the rate of 0.54 gallon per square yard. The preparation itself was, therefore, applied at the rate of 0.27 gallon per square yard. The section treated was 615 feet in length and 16 feet in width, giving a total of 1,093 square yards. The mixture was fairly well absorbed by the road, but a small amount was lost by drainage to the gutters. This application was made on March 17. Until the middle of May the results obtained from this treatment were quite satisfactory; the dust was successfully laid and the road surface well bound. Rains seemed to wash out the material much less than might have been expected. About May 15 the road showed signs of becoming dusty and was watered for a number of times. On June 1 another treatment with the sulphite liquor preparation in a 20 per cent dilution was given for a width of 12 feet in the center of the road. This application was made at the rate of 0.366 gallon of solution or 0.073 gallon of the preparation per square yard, and 820 square yards were thus covered. The cost of this experiment, together with experiments 2, 3, 4, and 5, are given on pages 3–4. While no charge was made for this material, it is figured at a minimum cost of 12 cents per gallon, delivered at the road.

Experiment No. 2.—Crude Waste Sulphite Liquor.

The road treated in this experiment and in the three following is a branch of that described under experiment No. 1, and runs nearly parallel to Fourteenth street. It does not, however, receive quite as much travel as the former. A crude waste sulphite liquor obtained from a pulp and paper company was applied at the rate of 0.5 gallon per square yard. As only one barrel of this material was available for use, it was sprinkled upon the road by means of common garden watering pots and "broomed" into the road surface. Application was made for a width of 12 feet, and 90 square yards of surface adjoining the first section were treated. The material was readily absorbed by the road, but did not appear to be as satisfactory a binder as the first preparation.

Experiment No. 3.—Crude Waste Sulphite Liquor.

This experiment was made in the same manner as experiment No. 2, with a sulphite liquor of 1.049 specific gravity (25° C.), obtained from another pulp and paper company. The rate of application was

0.5 gallon per square yard, and 90 square yards of roadway, adjoining section 2, were treated. This material was even more readily absorbed than that described in experiment No. 2, and seemed to produce a less satisfactory surface condition.

Experiment No. 4.—Concentrated Waste Sulphite Liquor.

In this experiment a concentrated liquor of 1.220 specific gravity (25° C.), obtained from a third pulp and paper company, was applied in the same manner as described in experiment No. 2. The liquor was, however, diluted with an equal volume of water, and the mixture thus produced was applied at the rate of 0.44 gallon per square yard. Twenty-two hundredths of a gallon of the original liquor were therefore consumed per square yard. A section of 114 square yards, adjoining section 3, was treated with this material, and the appearance of the road after treatment was quite similar to that produced by the use of the first preparation.

Experiment No. 5.—Concentrated Waste Sulphite Liquor.

This experiment was identical with experiment No. 4, except that the material was used in full strength. A section of 45 square yards was thus treated, and one-half of a gallon of the liquor was applied per square yard. It was not readily absorbed by the road, but after being "broomed" in produced a well-bonded surface.

COST DATA.

While the cost data can not be accurately figured, owing to the fact that no charge was made for material and that a number of engineer students took part in the work, the following is an approximation of the cost of eight-hour labor for the various experiments.

Table 1.—*Cost of labor in experiment No. 1 at Washington, D. C.*

Two laborers for bailing liquor, $\frac{3}{8}$ day, at $2	$1.50
One sprinkling cart, $\frac{3}{8}$ day, at $5	1.88
Total	3.38
Cost of labor per square yard (1,093 square yards total), first application	.0031
Approximate cost of material per square yard, first application	.0324
Total	.0355
Two laborers for bailing liquor, $\frac{1}{16}$ day, at $2	.25
One sprinkling cart, $\frac{3}{16}$ day, at $5	.94
Total	1.19
Cost of labor per square yard, second application	.0011
Approximate cost of material per square yard, second application	.0088
Total	.0099
Total cost per square yard	.0454

TABLE 2.—*Cost of labor in experiments Nos. 2, 3, 4, and 5 at Washington, D. C.*

Four laborers, ⅜ day, at $2	$2.00
One foreman, ⅜ day, at $3	.75
Total	2.75
Cost per square yard (339 square yards total)	.0081

SUMMARY OF EXPERIMENTS CONDUCTED AT WASHINGTON, D. C.

The use of crude waste sulphite liquors as described under experiments Nos. 2 and 3 proved but little more effective than water so far as laying the dust was concerned. For the first six weeks experiments Nos. 4 and 5 were as satisfactory as experiment No. 1, but owing to lack of material it was impossible to make a second application. With the exception of No. 1 all of these experiments were made upon such short stretches of road that no very definite conclusions could be drawn, but all indications point to the fact that the application of a solution of about 1.13 specific gravity at the rate of approximately 0.5 gallon per square yard is fully as effective as the more concentrated material. The second application described under experiment No. 1 laid the dust satisfactorily for a period of six weeks, after which the road slowly reverted to its original condition, although the excellent binding value of the material was apparent for some time later. From these experiments it would seem that crude waste sulphite liquor in single applications has but little value for road treatment, but that the concentrated material may be classed as a temporary or semipermanent dust preventive and road binder. It is possible, however, that, if crude liquor were applied daily as in ordinary water sprinkling, its use would prove economical in localities where it is produced, and that the base would concentrate in the road and eventually become a valuable binder.

EXPERIMENTS AT YOUNGSTOWN, OHIO (1909).

SLAG, SLAG AND LIME, SLAG AND WASTE SULPHITE LIQUOR PREPARATION, AND SLAG AND TAR.

During the summer of 1909 the Office of Public Roads, in cooperation with the Carnegie Steel Company, conducted a series of experiments at Youngstown, Ohio, to determine the best method of utilizing slag for road construction.

In the reduction of iron ores, the iron as it melts settles to the bottom of the furnace, while the impurities unite with the fluxing material to form what is known as blast-furnace slag. While the iron varies little in composition, the slag is by no means as uniform, owing to variations in the ore and flux. This slag is usually drawn off in a molten condition into large ladles holding about 140 tons each.

Sometimes it is run into a large vat of water to form what is known as granulated slag, a fine, crispy, glassy product, which is often used as a substitute for sand in concrete mixtures. Sometimes the slag is partially cooled in the ladle. When this is turned out and exposed to the air, or when a stream of water is thrown upon the cake, it rapidly breaks down into a fine dust of crystalline structure. As a rule the cars are hauled along a track to the edge of a bluff, where the ladles are dumped, allowing the slag to run out in thin layers to cool. The surface of the slag bank soon solidifies, but, where the product is poured from several large furnaces, the banks formed remain warm for a long time. It is generally believed that a slag bank should be allowed to season for at least two years before the slag is used.

It is evident that slag, even in the same bank, may vary greatly in composition, in hardness, and in structure. Where slag is deposited in large banks, it is most easily excavated by means of a steam shovel which starts at the bottom and plows up through the material, breaking up and, at the same time, mixing the different layers. One-third of the slag obtained in this manner at Youngstown was found to pass a $\frac{3}{4}$-inch screen. Of the coarser material about one-third was less than $1\frac{1}{2}$ inches in greatest diameter, while only a very small per cent was over $3\frac{1}{2}$ inches.

Most of the iron produced in the blast furnaces is converted into steel by various processes. In one process the crude metal is further purified in what is known as open-hearth furnaces. Here again a flux is used which rises to the surface of the molten mass as slag. This slag is run into small cars and formed into cakes about 6 feet square by 18 inches deep. When cold, these cakes are taken to a "skull-cracker" and broken up in order to separate the large amount of scrap iron which is always present. The utilization of this slag has been very limited, although it possesses many desirable properties, such as extreme hardness, toughness, and, frequently, excellent cementing properties. In the separation process a small amount breaks up into pieces less than one-fourth inch in size, usually with a large per cent of "man size" remaining.

A number of other slags are also formed in different processes of manufacturing steel, but usually in smaller quantities.

In the experiments at Youngstown the blast-furnace slag was taken from a bank that had aged for about two years and the material of which came from six furnaces of the same type. A steam shovel was used to load the slag from the bank into large gondola cars and these cars were drawn to a gravity screen, where the slag was dumped into a chute and passed over the screen to separate it into proper sizes. At first a $3\frac{1}{2}$-inch screen was used. The finer screenings fell into one car, while the coarser fell into another. The latter material,

as a rule, was very soft and crumbly, and was discarded, while the former was reserved until an amount sufficient for the work was obtained. As the slag could be passed over only one screen at a time, this proved to be a costly operation. The screened slag eventually obtained was quite uniform in character. After it had been properly sized, it was taken by rail to a siding about 1½ miles from the road upon which it was to be used. Here it was loaded into wagons and hauled to the road.

The road improved was located just outside the city limits on Belle Vista avenue, running south from Mahoning avenue, for a distance of 2,754 feet. The soil was a gravelly clay, sticky when wet and dusty when dry. The road was level for only 100 feet, while the contour elsewhere was rolling. The maximum grade was 4.5 per cent. This road is used by the farmers in hauling their produce to town and sustains also a heavy automobile and a light carriage traffic. As the county of Mahoning did all the grading before the Office of Public Roads commenced work, no cost data were kept for this item. Grading was done by contract at a cost of 22 cents per cubic yard for excavation. The total cost of excavation for the entire road, including the cost of retaining walls, amounted to over $2,000.

Experiment No. 1, Section No. 1.—Blast-Furnace Slag Macadam.

Section No. 1 was constructed as in regular macadam work. The first course consisted of blast-furnace slag ranging from 3½ inches to 1½ inches in diameter, laid loose to a depth of 9 inches and rolled until firm. This material was laid for a distance of about 100 feet on a part of the second section by mistake, and after it had been rolled a considerable amount of material was hauled over it. Though each teamster drove in the same track, only very small ruts were formed—an indication that the coarse slag was firmly keyed together. The second course was laid 4 inches deep at the center and 2½ inches at the side, with the same kind of material, varying from ¾ inch to 1½ inches in size. This was rolled until smooth, but it did not become absolutely firm until the top course of screenings ranging from three-eighths inch to dust had been applied. After spreading the screenings and rolling slightly in order to fill the voids as completely as possible with the fine material, water was applied in the usual way, by means of a sprinkler, and the rolling was continued. In a very short time the water began to run off the surface, which then became quite solid. As the road dried out, however, the surface became crumbly and required additional rolling and sprinkling. When the work was completed, about the middle of August, this section was in good condition except for one or two small places. From the behavior of this material indications point to the advisability of sprinkling the surface

every day for about ten days in order to develop the full binding value of the slag screenings.

The cost data for all of the Youngstown experiments are given on page 10.

Experiment No. 2, Section No. 5.—Blast-Furnace Slag.

This experiment was made at the suggestion of the Carnegie Steel Company, who wished to ascertain if the cost of construction could be lowered without producing bad results. The first course of section No. 5 was composed of $\frac{3}{4}$-inch to $3\frac{1}{2}$-inch slag, laid 12 inches deep at the center and 9 inches at the side. Owing to the great range in sizes and the method of screening, there was considerable lack of uniformity between different loads of the material. Since this course was thick, it required more rolling than the other first courses. The road consisting of this single course was finished in the same manner as described under experiment No. 1, after slag screenings running from three-eighths inch to dust had been applied. The surface was well bonded when inspected at the beginning of last fall.

Experiment No. 3, Section No. 6.—Blast-Furnace Slag.

The first course of section No. 6 was laid 9 inches deep with slag varying in size from $3\frac{1}{2}$ inches to dust. This material, like that employed for experiment No. 2, was lacking in uniformity. The second course, 6 inches deep at the center and 4 inches at the side, was composed of $3\frac{1}{2}$-inch to $\frac{3}{4}$-inch material. Each course was well rolled, and the section was finished in the same manner as in experiment No. 2 and with similar results.

Experiment No. 4, Section No. 7.—Blast-Furnace and Open-Hearth Slag.

Section No. 7 was constructed in the same manner as section No. 6, except that fine open-hearth slag screenings ranging in size from $\frac{1}{4}$-inch to dust were used in place of the blast-furnace slag screenings. When puddled this material set very quickly and produced a firm surface. The open-hearth slag was prepared by crushing the slag left at the "skull-cracker" after the "man-size" blocks had been removed. Care was taken to prevent iron from entering the jaws of the crusher. After leaving the crusher, it was placed in a dry roll mill, where it was ground to fine screenings, a large percentage of which became dust. This material was taken to the road and spread about $1\frac{1}{2}$ inches deep. The addition of free lime, as described under experiment No. 5, was not considered necessary, as these slags when finely powdered frequently have high binding properties, owing to the presence of free lime and silicate minerals which when moistened produce a true hydraulic set.

Experiment No. 5, Section No. 2.—Blast-Furnace Slag and Lime.

Section No. 2 was constructed in the same way as section No. 1, except that 5 per cent of powdered quicklime was mixed with the slag screenings, from ⅜ inch in size to dust. This addition was made to hasten and increase the bond of the road surface by the chemical action of the caustic lime, when freshly slaked, on the mineral constituents of the slag dust. In mixing the two, the fine slag was measured out on a mixing board and the 5 per cent of lime spread on the top. This was turned twice and then loaded on wheelbarrows or shoveled directly upon the road. The slag had been dumped, in separate loads, on one side of the road, and, as the screenings were spread, the mixing board was moved ahead about 30 feet at a time. Upon being sprinkled and rolled, the surface bonded very quickly and became solid. It did not become crumbly or "calk up" under traffic as did section No. 1. It was observed that better results were obtained from the use of very fine screenings than from coarser material.

Experiment No. 6, Section No. 3.—Blast-Furnace Slag and Waste Sulphite Liquor Preparation.

Section No. 3 was constructed in the same manner as section No. 1, except that a concentrated waste sulphite liquor preparation of 1.273 specific gravity, similar to that used in the experiments at Washington, D. C., was mixed with water and used to puddle the surface. The sprinkler, after having been filled with water, was conducted over sections Nos. 1 and 2 and enough water sprinkled on these sections to leave space in the tank for the desired amount of the sulphite liquor. After this material had been poured into the sprinkler, a hoe was used to mix the two together thoroughly. The mixture was then applied to the road and, as the solution tended to run toward the gutters, care was taken that the center should receive the heaviest treatment. At first one part of the liquor to seven parts of water was used, and this produced a very thin solution, which penetrated several inches into the wearing surface. As the voids were gradually filled, it became necessary to add more of the liquor to each tank of water to decrease the rate of flow in order that the liquid might not run off the road. The last mixture used was composed of one part of water to one part of the liquor and only one-half of a tankful was applied at a time. This treatment was repeated from day to day as the surface absorbed the material. It was found necessary to roll the road shortly after sprinkling, because otherwise the surface soon became so sticky that it would pick up under the wheels of the roller. After about one gallon of the sulphite liquor had been applied to the square yard, a very smooth surface was produced which did not "calk up" under traffic. A few days later the surface was found to be badly cracked and blis-

tered for a depth of one-eighth inch, but the material below was solid. The section was sprinkled with water and well rolled again, leaving the road in good shape, but not as smooth as it was before.

Experiment No. 7, Section No. 4.—Blast-Furnace Slag and Refined Coke-Oven Tar.

In section No. 4 the first course was laid in exactly the same manner as described for section No. 1. The second course was laid 4 inches deep and consisted of a mixture of three parts of slag from 1½ inches to ¾ inch in diameter to one part of slag varying from three-eighths inch to dust, with about 6 per cent of tar. The slag was heated in a large pan until dry and warm to the hand. One-half of the pan was used for heating each size of material. The coarse slag was first shoveled into a gauge placed upon the mixing board and the finer slag was placed on top. After the two had been turned twice, the tar, which had been heated in a two-barrel pot, was poured over the slag and the whole was well mixed. The mixture was then shoveled into wheelbarrows and carried to the point at which it was spread upon the road. The mixture was rather dry and, after rolling, it was found necessary to flush the surface with tar. Two large sprinkling cans were used for this purpose, after the holes in the nozzles had been enlarged. About one-fourth gallon of tar was applied to the square yard, making a total of about 1½ gallons. A thin coat of slag (three-eighths inch to dust) was now spread over the surface and rolled in to fill all voids and to take up any surplus tar.

This tar was obtained from a by-product coke-oven plant at Sharon, Pa., where it was also refined by distilling off about 17 per cent of the lighter oils and water. Its characteristics are shown in the following table. When last inspected, at the beginning of fall, this section was in excellent condition.

Table 3.—*Analysis of refined coke-oven tar.*[a]

Specific gravity 25°/25° C		1.217
Float test at 32° C. (time)		1′ 25″
Per cent of free carbon (insoluble in CS_2, air temperature)		13.11
Distillation:	Per cent by volume.	Per cent by weight.
Water	0.0	0.0
First light oils to 110° C.	.0	.0
Second light oils 110°–170° C.	[b] 3.8	3.2
Dead oils 170°–270° C.	[c] 26.6	23.4
Pitch residue	[d] 69.6	73.4
	100.0	100.0

[a] Viscous.

[b] Distillate practically solid when cold.

[c] Distillate showed about one-third its volume precipitated solids when cold.

[d] Pitch residue, hard, brittle, fairly lustrous.

TABLE 4.—*Materials and cost data of experiments at Youngstown, Ohio.*

Description.					Quantities.				Cost data (cents per square yard).						Total cost.	
Experiment No.	Section No.	Binder.	Length of section (feet).	Area of section (square yards).	No. 1 slag (cubic yards per square yard).	No. 2 slag (cubic yards per square yard).	No. 3 slag (cubic yards per square yard).	Binder per square yard.	Slag on siding.	Hauling and laying slag.	Binder.	Applying binder.	Rolling and sprinkling.	Miscellaneous.	Cents per square yard.	Entire section.
1	1	Slag screenings	500	777	0.250	0.090	0.042	....	18.95	20.15	....	....	7.42	......	46.52	$361.46
2	5	.....do	300	456	.292	....	.042	....	16.60	17.60	....	....	9.14	......	43.34	197.63
3	6	.....do	325	506	.250	.139	.042	....	21.41	22.75	....	....	7.80	......	51.96	262.92
4	7	Open-hearth slag screenings	325	506	.250	.139	.042	....	21.41	22.75	....	....	6.05	......	50.21	254.06
5	2	Slag screenings and lime	500	777	.250	.090	.042	[a] 4.5	18.95	20.15	0.83	2.46	5.79	......	48.18	374.35
6	3	Slag screenings and sulphite liquor	500	777	.250	.090	.042	[b] .901	18.95	20.15	13.88	.95	7.38	......	61.31	476.38
7	4	Refined coke-oven tar	300	456	.250	.090	.022	[b] 1.545	17.97	19.10	13.49	12.72	4.17	1.00	68.45	312.13

[a] Pounds. [b] Gallons.

EXPERIMENTS AT ITHACA, N. Y. (1909).

TAR, OIL, ARTIFICIAL ASPHALT PREPARATIONS, BRICK, CEMENT, AND SLAG.

The experiments at Ithaca were conducted by the Office of Public Roads in cooperation with Cornell University for the purpose of ascertaining the relative value of different road binders applied in a number of ways under given conditions. According to previous arrangements, the university furnished all stone, machinery, and necessary labor; various manufacturers donated the bitumens, brick, cement, and slag; and the Office of Public Roads paid freight charges on all donated material and furnished supervision of the work. When so desired the manufacturers had a representative present during the application of their material.

In the experiments where bitumens were employed as binders an attempt was made to try out all materials according to two methods of construction, known as the penetration method and the mixing method. Work was begun so late in the summer, however, that it was found impossible to finish it before winter. It was thought best, therefore, to stop work in December and wait until spring to complete the experiments.

With the exception of the brickwork no section was selected in advance for any given product, but each material was used in the order of its arrival at Ithaca upon the first section available. The brick was purposely laid on that section of road subject to the heaviest traffic. The sections mentioned in the following descriptions run east from the west extremity of the road. The road selected for these experiments is known as the Forest Home drive, and, beginning at Central avenue just west of Sibley College, runs east to the city limits, 3,000 feet. Arrangements were made to use as much of the state road No. 681, running from Ithaca to Dryden, as experiments required. This state road is a continuation of the one originally selected for the experiments. During 1909, about 3,900 feet of roadway were laid.

The road is subjected to a rather heavy automobile traffic and a considerable amount of country traffic the year around. That part lying between Central avenue and the bridge (about 800 feet) is subject to a large amount of heavy hauling. During the winter months the frosts are very heavy and the road is generally covered with snow.

From station O at the west end to station 8+50 the road passes over a well-formed foundation of gravel. Street-car tracks cross the road from East avenue at station 6+15 and these run parallel to the road as far as station 7+50. Here a 6 per cent grade extends to

station 9 + 50. From station 8 + 50 to station 12 the old road had been cut to reduce grades and exposed a layer of clay-bearing quicksand, which disappeared at station 13. At this place the earth was excavated to a depth of about 4½ feet and refilled with shale shuck. This filling, when well rolled, gave a very fair foundation. A 5-inch tile was placed at the bottom of this excavation, next to the hill, on the south side of the road running to station 6 + 75, for the purpose of draining the subgrade and preventing seepage from the sidehill. For the same purpose a 5-inch tile was placed on the south side of the road from station 12 to station 15 + 50. This foundation held up well when the road was completed. From station 15 to station 22 the subgrade was excellent. That part from station 15 to station 20 lies so that the sun strikes it throughout the day. At station 22 quicksand was again encountered on the right side of the road looking east. This sand gradually extended into the road, underlying its entire width, from station 25 + 50 to station 29. A 5-inch tile was placed on the road next to the hill running from station 27 to station 21, and, in like manner, a 4-inch tile from station 27 to station 30. As the quicksand was not as bad as on the first hill, the university had previously constructed an ordinary macadam road at this place, depending upon the tile and additional 4 inches of stone to make the road firm. As the road was being completed, however, it was noticed that the foundation waved somewhat under the roller. When finished the road appeared quite firm and, if the tiles are kept open, the foundation should continue to improve. All tile for this work was covered with either shale shuck or ashes. The road lying between stations 30 and 39 passes over an old roadbed where the subgrade is very solid. Most of the road runs along the bank of Beebe Lake and is about 20 feet above the water.

The labor employed was unskilled and consisted of the regular campus force, together with a few extra men. Common labor was figured at $1.50 per 9-hour day, foremen at $3, and double teams at $3.50. The stone used was a hard blue limestone, costing 65 cents per ton f. o. b. cars at the shipping point about 60 miles away. Freight on this stone amounted to 50 cents per ton. The cost of constructing the experimental sections described below is of course excessive, owing to the shortness of the sections and the constant rearrangement of labor which was made necessary by the variety of work. The crude machinery and heating apparatus which had to be used also added greatly to the cost.

The road was 16 feet wide and had 3-foot shoulders on each side. When the Office took charge of the work the first course of stone for a distance of 3,000 feet had been laid by the university. This course was composed of crushed stone, ranging from 1½ to 3½ inches, placed 4 inches deep when loose. After rolling, a sand filler was applied,

until all voids were filled, and the road was again well rolled. A $\frac{3}{4}$-inch crown was adopted for all of the bitumen work. The bitumens were heated in a 10-barrel tank fitted with a fire box and mounted on wheels. Scrap wood was used for fuel. The bitumens were fed into the tank through a manhole in the top and, when heated, were drawn off through a spigot placed just over the fire box at the rear of the wagon. Owing to this arrangement the entire contents of the tank had to be brought to the desired temperature before drawing off. If any attempt was made to feed in fresh material during application, the cold bitumen, by settling on the bottom, would clog the valve. Two 2-barrel iron soap kettles were also used for heating the bitumen while the large tank was being recharged, but in spite of this the work was often delayed for lack of hot material. When the bitumen was sufficiently soft to flow, the barrels were rolled on skids to the top of the tank, the head knocked in, and the material drained into the tank. As there was only sufficient room to drain one barrel into the tank at a time, this operation consumed a great deal of time. Two flat $\frac{1}{8}$-inch steel stone heaters, each having a heating surface of 80 square feet, and a semicylindrical section of an old boiler were employed for heating the stone when required. The two former were used for heating coarse stone and the latter for screenings.

A portable concrete batch mixer of the old McKelvey type was used in mixing both the bitumen and the cement concrete. It was driven by a gasoline engine connected by a chain drive. In the bituminous mixtures segregation of the various sizes of stone occurred to some extent while the concrete was being discharged, as the coarse stone came out first, while the finer material stuck to the sides of the discharge funnel, without, however, completely clogging it. Wheelbarrows loaded as nearly alike as possible each time were used in proportioning and transporting the mineral aggregate from the heaters or storage pile to the mixer. An old 12-ton steam roller was used in the greater part of the work, but was later replaced by a new 10-ton roller.

Experiment No. 1, Section No. 1.—Refined Coal Tar—Penetration Method.

The section treated in this experiment was 300 feet long and began at station O. The wearing course of stone, which ranged in sizes from $1\frac{1}{2}$ inches to $\frac{1}{2}$ inch in its largest dimensions, was laid 4 inches deep when loose. As this stone contained considerable fine material and was damp when laid, a steel harrow was used to stir it until dry and to work all dust to the bottom. This proved to be a very satisfactory method and left a fairly even surface of coarse stone on top, which was then rolled until firm. The binder used in this experiment was a coal tar, showing the following properties:

TABLE 5.—*Analyses of refined coal tars.*

	Heavy.[a]		Light.[b]	
Specific gravity 25°/25° C	1.248		1.215	
Float test at 32° C (time)	9′ 36″		1′ 5″	
Per cent of free carbon (insoluble in CS_2, air temperature)	23.95		19.36	
	Per cent by volume.	Per cent by weight.	Per cent by volume.	Per cent by weight.
Distillation:				
Water	0.0	0.0	0.0	0.0
First light oils to 110° C	.0	.0	.2	.2
Second light oils, 110°–170° C	[c] 1.2	.9	[d] 3.2	2.5
Dead oils, 170°–270° C	[e] 20.2	16.7	[f] 29.6	25.1
Pitch residue	[g] 78.6	82.3	[g] 67.0	72.0
	100.0	99.9	100.0	99.8

[a] Extremely viscous.
[b] Viscous fluid; sticky.
[c] Distillate showed about one-half its volume precipitated solids when cold.
[d] Distillate showed about three-fourths its volume precipitated solids when cold.
[e] Distillate showed about two-fifths its volume precipitated solids when cold.
[f] Distillate showed about four-fifths its volume precipitated solids when cold.
[g] Pitch residue hard, brittle, slightly lustrous.

This material was very viscous and flowed slowly from the barrel when cold. In order to facilitate handling it was found advisable to warm the tar for some time before attempting to load the heating tank by placing the barrels near a coke fire, built in a small portable furnace. The tar was finally heated in the tank to between 250° and 280° F., and then drawn off into coal scuttles fitted with strips of metal which were riveted across their spouts, so as to give an opening 4½ inches across and one-half inch wide. The hot tar was then poured upon the prepared road surface at the rate of approximately 1½ gallons per square yard. The surface was given a light coat of screenings (one-half inch to dust) and then rolled; and more screenings were applied from time to time until the surface became firm. The road was allowed to remain in this condition for about two weeks, after which the surplus screenings were swept from the surface with rattan hand brooms. A lighter tar than that previously used was then heated, poured upon the surface, and "broomed" in. The properties of this tar, which was applied at the rate of approximately one-half gallon per square yard, are also given in Table 5. Screenings were again applied in sufficient quantity to fill all surface voids and take up the surplus tar. This made the surface smooth and solid when rolled.

EXPERIMENT NO. 2, SECTION NO. 2.—REFINED COAL TAR—MIXING METHOD.

Section No. 2 adjoins section No. 1 and extends east for a distance of 300 feet. In this experiment crushed stone ranging in size from 1½ inches to ½ inch was laid to a depth of 1½ inches on the foundation course and rolled until firm. Crushed stone heated in the manner previously described was proportioned as follows: Six parts, by weight, of from 1½ to ½ inch stone to one part from ½ inch to dust. These two sizes of stone were measured in wheelbarrows and carried to the mixer.

The coarse stone was first dumped into the mixer and about 6 per cent, by weight, of hot tar added. After the mixer had made two turns, the screenings were dumped in and mixing continued until the stone had become thoroughly covered with tar. The mixture was dumped upon a platform where it was shoveled into wheelbarrows, taken to the road, and spread to a depth of 2½ inches. The mineral aggregate as laid was not entirely satisfactory, owing to the segregation that took place upon being discharged from the mixer, and to the fact that the stone furnished for this work was not uniform. Part of the larger size consisted entirely of stone 1½ inches in size, while part contained much fine material. The tar used on this section was the same as the heavy product described under experiment No. 1.

This course was well rolled after a light coat of stone chips one-half to one-fourth inch in size was spread over the surface to keep the tar from sticking to the roller wheels. While rolling, more chips were added as required. When thoroughly rolled, the surface was painted with about one-half gallon of tar to the square yard. Enough stone chips were then added to take up all surplus tar and fill the voids. This section, when finished, presented a smooth, firm surface. In about two months, however, one spot showed signs of raveling. Four small patches were made at this place by cutting out the defective surface and refilling with hot stone. Tar was then poured over the new stone and the surface well tamped. Sections 1 and 2 were opened to traffic shortly after completion.

Experiment No. 3, Section No. 4.—Artificial Oil Asphalt—Mixing Method.

Section No. 4 extends from station 9+25 to station 12. The wearing course was mixed in the same manner as in experiment No. 2, except that an artificial oil asphalt, heated to between 250° and 300° F., was used in place of the tar. Upon examination this material showed the following properties:

Table 6.—*Analysis of artificial oil asphalt* [a] *used in experiment No. 3.*

Specific gravity 25°/25° C	0.996
Melting point °C. (cube method)	55
Float test at 65° C. (time)	5′ 14″
Penetration (No. 2 N, 5 seconds, 100 grams, 25° C.)	82°
Per cent of loss at 163° C., 5 hours (20 grams)	1.97
Penetration of residue (as above)	64°
Per cent of total bitumen insoluble in 86° paraffin naphtha	23.96
Per cent of fixed carbon	8.42
Per cent of bitumen soluble in CS_2, air temperature (total bitumen)	99.69
Organic matter insoluble	.11
Inorganic matter	.20
	100.00

[a] Dense, semisolid.

This product was shipped in sheet-iron drums, holding about 56 gallons each. In handling it was found convenient to cut the ends of the drums free and also to cut a seam down the side. The drums were then rolled upon two small iron rails over a fire. In this manner a thin layer of melted oil was formed next to the metal and this permitted the casing to be easily removed. The cakes of asphalt were then cut up by means of a wire and thrown into the tank heater. After coming from the mixer, the coated stone was shoveled into dump wagons and hauled 500 feet to the road, where it was dumped upon a board and shoveled into place. Owing to this method of handling, a much more uniform mixture was obtained than in experiment No. 2. It was found that the course of bitumen-coated stone could be rolled before adding stone chips. This section did not require a paint coat of bitumen and was completed by rolling in stone chips as in the first two sections, in order to produce a finished surface.

EXPERIMENT NO. 4, SECTION NO. 12.—ARTIFICIAL OIL ASPHALT—MIXING METHOD.

Section No. 12 is a part of the state road No. 681. The foundation course of crushed limestone running from 2 to 4 inches in size was laid $5\frac{2}{3}$ inches loose and rolled solid after a sand filler had been added. The course of bitumen-covered stone was laid directly upon this foundation in the same manner as described in experiment No. 2, and an artificial asphalt showing the following characteristics was employed as a binder.

TABLE 7.—*Analysis of artificial oil asphalt* [a] *used in experiment No. 4.*

Specific gravity 25°/25° C	0.964
Float test at 100° C. (time)	1′ 27″
Melting point °C. (cube method)	67°
Penetration (No. 2 N, 5 seconds, 100 grams, 25° C)	168°
Per cent of loss at 163° C., 5 hours (20 grams)	0.85
Float test on residue at 100° C. (time)	1′ 29″
Per cent of total bitumen insoluble in 86° paraffin naphtha	22.0
Per cent of fixed carbon	8.60
Per cent of bitumen soluble in CS_2, air temperature (total bitumen)	99.74
Organic matter insoluble	.12
Inorganic matter	.14
	100.00

Owing to cold, damp weather this work was very much handicapped. The oil-asphalt was shipped in 42-gallon barrels which had been coated inside with whitewash. This made it possible to strip the staves from the material so that it could be readily cut up by means of a wire. This course did not bond well and had to be painted in order to obtain a satisfactory surface. About $1\frac{1}{2}$ gallons of asphalt were used to the square yard.

[a] Dense, semisolid.

Experiment No. 5, Section No. 5.—Refined Semiasphaltic Oil—Penetration Method.

The surface of section No. 5 was constructed in the same manner as No. 1, except that a rather fluid semiasphaltic oil, having the properties given below, was used.

Table 8.—*Analysis of refined semiasphaltic oil.*[a]

Specific gravity 25°/25° C	0.955
Float test at 32° C. (time)	58″
Flash point °C. (open cup)	119°
Burning point °C. (open cup)	155°
Per cent of loss at 163° C., 5 hours (20 grams)	13.4
Float test on residue[b] at 35° C. (time)	3′ 27″
Per cent of total bitumen insoluble in 86° paraffin naphtha	14.99
Per cent of fixed carbon	6.35
Per cent of bitumen soluble in CS_2, air temperature (total bitumen)	99.82
Organic matter insoluble	.11
Inorganic matter insoluble	.07
	100.00

This material was heated to between 210° and 240° F. It could be easily handled and run from the barrels into the tank-wagon without trouble. Application was made at the rate of about 1½ gallons to the square yard. It was found unnecessary to paint this course, since the oil worked to the surface under the action of the roller after applying the stone chips. The section was in good condition on December 2.

Experiment No. 6, Section No. 6.—Semisolid Refined Semiasphaltic Oil—Penetration Method.

Section No. 6 was built in the same manner as section No. 5, except that a different semiasphaltic oil was used. The results of the examination of this material are given in the following table under No. 1:

Table 9.—*Analyses of semisolid refined semiasphaltic oils.*[c]

	No. 1.	No. 2.
Specific gravity 25°/25° C	0.985	0.989
Float test 65° C. (time)	1′ 54″	1′ 56″
Melting point ° C. (cube method)	....	36°
Penetration (No. 2 N, 5 seconds, 100 grams, 25° C.)	247°	196°
Per cent of loss at 163° C., 5 hours (20 grams)	0.00	0.04
Penetration of residue (as above)	160°	142°
Per cent of total bitumen insoluble in 86° paraffin naphtha	17.41	20.02
Per cent of fixed carbon	11.20	11.53
Per cent of bitumen soluble in CS_2, air temperature (total bitumen)	99.86	99.77
Organic matter insoluble	.09	.05
Inorganic matter	.05	.18
	100.00	100.00

[a] Viscous, slightly sticky.

[b] Character of residue, slightly fluid, somewhat sticky.

[c] Semisolid, sticky.

In this case it was found impossible to pour the oil from the wooden barrels, and it was therefore necessary to knock off the hoops and throw the barrels, with their contents, into the small heating kettles. The oil was then heated to about 350° F. and the staves were used as fuel as they floated to the top. The surface of this section was not painted. Stone chips were applied and rolled in, making a smooth, firm surface, which was in good condition when last inspected.

The manufacturers had shipped two products, one to be used according to the penetration method and the other according to the mixing method. Owing to great similarity in the markings on the barrels, and to the fact that there was hardly a perceptible difference in the appearance of the materials themselves, over 200 feet of the section were laid with the product intended for the mixing method before the mistake was called to the attention of the engineer in charge by the agent of the company. The remaining 90 feet were laid with the material intended for the penetration method described in the analysis as No. 2. When last inspected there was no apparent difference in the results obtained from the two products.

Experiment No. 7, Section No. 8.—Refined Water-Gas Tar—Penetration Method.

Section No. 8 was constructed in the same manner as section No. 6, except that refined water-gas tar was used instead of the oil. Both the tank-wagon and the two kettles were used in heating this material, which was first warmed in the barrels, as described in experiment No. 1, and then poured into the kettles or tank and raised to a temperature of 275° C. The characteristics of this material are shown in Table 10.

The tar-coated course, after stone chips had been applied, rolled down into good condition. On part of this section more tar was applied than had been intended, during the unavoidable absence of the engineer in charge. Owing to the excess of tar the surface did not require a paint coat; in fact, a large amount of stone screenings was found necessary to take up the surplus tar.

Table 10.—*Analysis of refined water-gas tar.*[a]

Specific gravity 25°/25° C		1.158
Float test at 32° C. (time)		5′ 10″
Per cent of free carbon (insoluble in CS_2, air temperature)		1.15
Distillation:	Per cent by volume.	Per cent by weight.
Water	0.0	0.0
First light oils to 110° C	.4	.3
Second light oils 110°–170° C	.7	.5
Dead oils 170°–270° C	[b] 33.2	29.1
Pitch residue	[c] 65.7	69.4
	100.0	99.3

[a] Viscous, sticky.

[b] Distillate showed a trace of precipitated solids when cold.

[c] Pitch residue hard, brittle, and lustrous.

Experiment No. 8, Section No. 9.—Refined Semiasphaltic Oil—Penetration Method.

On section No. 9 a viscous semiasphaltic oil (see Table 11) was used, according to the same method as described in experiment No. 5. This oil was applied at the rate of 2 gallons per square yard, at the request of the manufacturers' agent, who was present at the time. The oil sweated to the surface upon rolling, and it will undoubtedly be necessary to apply stone screenings from time to time until all excess of oil is taken up. The section was left in good condition on December 2.

Table 11.—*Analysis of refined semiasphaltic oil.*[a]

Specific gravity 25°/25° C	0.993
Float test at 32° C. (time)	2′ 20″
Flash point, ° C., open cup	234°
Burning point, ° C., open cup	298°
Per cent of loss at 163°, 5 hours (20 grams)[b]	.90
Float test on residue at 35° C. (time)	4′ 35″
Per cent of total bitumen insoluble in 86° paraffin naphtha	12.70
Per cent of fixed carbon	9.45
Per cent of bitumen soluble in CS_2, air temperature (total bitumen)	99.65
Organic matter insoluble	.26
Inorganic matter	.09
	100.00

Experiment No. 9.—Section No. 10.—Refined Water-Gas Tar and Slag—Penetration Method.

Section No. 10 was only 100 feet in length. The top 4 inches were composed of open-hearth slag, crushed and screened to between three-fourths inch and 3 inches in the largest dimensions, and then rolled until firm. About 1 inch of from three-fourths to one-fourth inch crushed slag was then spread evenly over the surface and rolled down. A heavy refined water-gas tar, showing the following properties, was poured over this course in the usual manner.

Table 12.—*Analysis of heavy refined water-gas tar.*[c]

Specific gravity 25°/25° C		1.167
Float test at 32° C. (time)		22′ 11″
Per cent of free carbon (insoluble in CS_2, air temperature)		2.09
Distillation:	Per cent by volume.	Per cent by weight.
Water	0.0	0.0
First light oils to 110° C	0.5	0.4
Second light oils 110°–170° C	3.0	2.5
Dead oils 170°–270° C	[d] 29.0	25.2
Pitch residue	[e] 67.5	71.2
	100.0	99.3

[a] Viscous, fairly sticky.

[b] Character of residue, dull and granular.

[c] Very viscous, sticky.

[d] Distillate showed about one-tenth its volume precipitated solids when cold.

[e] Pitch residue, hard, brittle, and lustrous.

This tar was of such consistency that it had to be handled in the same manner as described for the semiasphaltic oil in experiment No. 6. Fine slag, from one-fourth inch to dust in size, was rolled into the tarred surface and made a smooth, firm road. After this section had been completed, mud was found coming through the surface in one place where the foundation was soft. About 2 square yards of the surface were, therefore, taken out and the mud removed and replaced with good gravelly soil well tamped. Slag was then applied and more tar added, after which the patch was tamped solid.

Experiment No. 10, Section No. 7.—Kentucky Rock Asphalt.

The stone for section No. 7 was laid to the same depth as in section No. 1. The bonding material in this case was Kentucky rock asphalt, obtained from the same source as that used in the experiment at Bowling Green, Ky., which was reported in Circular 89. Upon analysis this material showed the following characteristics:

Table 13.—*Analysis of Kentucky rock asphalt.*

Per cent soluble in CS_2, air temperature (total bitumen)	6.73
Per cent of mineral matter	93.27
Per cent retained on 10-mesh sieve	1.0
Per cent passing 10, retained on 20 mesh	3.0
Per cent passing 20, retained on 30 mesh	5.5
Per cent passing 30, retained on 50 mesh	43.0
Per cent passing 50, retained on 80 mesh	35.0
Per cent passing 80, retained on 100 mesh	4.5
Per cent passing 100, retained on 200 mesh	4.5
Per cent passing 200 mesh	3.5
	100.0
Extracted bitumen:	
Specific gravity 25°/25° C	1.027
Per cent of loss at 163°, 5 hours (20 grams) [a]	5.41
Per cent of mineral matter	1.76
Per cent of bitumen insoluble in 86° paraffin naphtha	18.10
Per cent of fixed carbon	10.83

The product was shipped in an open car. When shoveled into the wagons it was found necessary first to use picks to loosen up the material. Before spreading, the upper course of stone was rolled until firm and then the asphalt was shoveled from a dumping board into place to a depth of 1½ inches over the east half of the section. On the west half one-half inch was first applied. A harrow was then passed over the material for a few times in order to work it into the stone, after which the course was rolled once to smooth up the surface. The rock asphalt was then applied to a depth of 1 inch more on the west end and the whole surface rolled. During a cold spell of ten days it was found impossible to finish this surface satisfactorily, since it tended to crack under the roller. When the

[a] Residue semisolid, soft, sticky.

weather became warmer, however, it was finished off in good condition. When rolling it was found necessary to cover the roller wheels with dust in order to prevent the asphalt from picking up. On December 1 the road was in excellent condition and showed no signs of calking, as it had the first week after laying. No difference could be seen between the two halves of this section.

Experiment No. 11, Section No. 11.—Open-Hearth Slag.

Section No. 11 was constructed in the same manner as section No. 10, except that no bituminous material was employed; slag screenings from one-fourth inch in size to dust were used for a binder, as in ordinary macadam work. Owing to its hardness and the lack of very fine material or slag powder and to the rather soft subgrade, it was found impossible to obtain a good bond. The fine slag was composed mainly of gritty, sand-like particles, which would not pulverize under the roller and produce the very fine dust necessary to give satisfactory results. This would indicate that a certain proportion of the open-hearth slag screenings should consist of finely ground material in order to bind well. For the purpose of accelerating the binding properties of the slag through chemical reaction, as described in the Youngstown experiments with blast-furnace slag, unslaked lime was spread over the surface and rolled in. The surface was well watered, but did not show up as well as the slag work at Youngstown.

Experiment No. 12, Sections Nos. 15 and 14.—(*a*) Cement Concrete. (*b*) Bituminous-Surfaced Cement Concrete.

(*a*) The foundation course of section No. 15 was laid 4 inches deep and consisted of crushed limestone from 2 to 4 inches in size. The wearing course was composed of concrete made of one part Portland cement, two parts sand, and five parts stone. The results of the examination of this cement are shown in the following table:

Table 14.—*Examination of Portland cement.*

Specific gravity	3. 122
Per cent of magnesia (MgO)	3. 30
Per cent of sulphuric anhydride (SO_3)	1. 55
Fineness:	
Per cent retained on 100 mesh	4. 8
Per cent retained on 200 mesh	17. 8
Time of setting:	
Initial setting	2 hours 40 minutes.
Final setting	6 hours 30 minutes.
Tensile strength:	
Neat, 24 hours in moist air (pounds per square inch)	258
Neat, 7 days (1 day, moist air; 6 days, water) (pounds per square inch)	528
Neat, 28 days (1 day, moist air; 27 days, water) (pounds per square inch)	728
1 cement : 3 sand;[a] 7 days as above (pounds per square inch)	186
1 cement : 3 sand; 28 days as above (pounds per square inch)	275

[a] Standard Ottawa sand used.

Constancy of volume:

Pat in air 28 days .... Sound.

Pat in water 28 days .... Sound.

Pat over boiling water, 4 hours .... Sound.

The sand used was a fine, clean product, the best that could be obtained in the immediate vicinity. The stone was of the same kind as used throughout these experiments, coming in two sizes, one ranging from 1¼ to 2¼ inches, and the other from ½ to 1¼ inches. Two boxes, one holding 6 cubic feet and the other 1 cubic foot, were used to determine the proportions in which these two sizes could be mixed with the lowest percentage of voids. Six cubic feet of the two materials were measured out in varying proportions, mixed on a mixing board, and shoveled into the larger box, where the depth of stone was measured by a rule placed in one corner of the box before the stone was shoveled in. The mixed stone was leveled without reference to its depth before a reading was made. The following results were obtained from different trial mixtures.

TABLE 15.—*Results of trial mixtures of cement concrete.*

No. of mixture.	1¼-inch to 2¼-inch stone.	½-inch to 1¼-inch stone.	Depth in inches.
	Cubic feet.	*Cubic feet.*	
1	3	3	15.75
2	4	2	15.5
3	3½	2½	15.25
4	4	2	15.5
5	2½	3½	15.5
6	6	0	16.25
7	3¾	2¼	15
8	3¾	2¼	15

This shows for the mixtures tried that 3¾ parts of the 1½-inch stone to 2¼ parts of the ¾-inch stone gave the lowest percentage of voids. By taking eighteen shovelfuls of material to a wheelbarrow load, the proportions worked out roughly to two wheelbarrows of the covered stone, containing fifteen shovelfuls each, to one barrow load containing eighteen shovelfuls of the finer stone. These proportions were followed as nearly as possible in carrying out the work. The concrete was mixed in the mechanical mixer, hauled 300 feet in a dump wagon and dumped upon a mixing board, from which it was shoveled into place and raked with steel hand rakes to conform to the desired crown of the road. At first the concrete was made rather dry, but as it was found that the voids were not being properly filled, more water was added, and the mixture was then raked and tamped until the mortar flushed to the surface. After this the surface was rolled until fairly smooth with a concrete roller 2½ feet long by 18 inches in diameter. The finished surface, while somewhat rough, was uniform, except where the mixture was made too dry. Cold weather made it necessary to cover the

concrete with leaves immediately after it was rolled. The whole operation, from the time the concrete went into the mixer until it was covered up, averaged about forty minutes.

(*b*) The first 30 feet of section No. 14 were coated with the artificial oil asphalt described in experiment No. 4. This material was applied hot at the rate of 1 gallon per square yard and was covered with stone chips. The bitumen did not adhere very well to the cold, damp surface. After the concrete was laid the road was kept closed for about fifteen days, and on December 2 the entire road was in good shape, except in one place, where a retaining wall should be placed.

Experiment No. 13, Section No. 13.—Ash-Cement-Concrete Section.

The foundation course of section No. 13 was constructed in the same manner as section No. 12. At the request of Cornell University, a concrete composed of six parts of ashes from the college heating plant, two parts of sand, and one part of cement was prepared and laid in the manner previously described in experiment No. 12. This section was rolled with the small hand concrete roller until water flushed to the top. Upon setting, the road became hard and appeared quite satisfactory.

Experiment No. 14, Section No. 3.—Brick.

Section No. 3 extends from the inside of the west rail of the street-car track, crossing the road to station 9+25, a total of 526 square yards in all. After the grading had been completed, a foundation course was laid in the same manner as described for sections Nos. 1 and 2, except that the voids were well filled with screenings from one-fourth inch in size to dust, instead of with sand. Where the car tracks cross the road, the foundation was prepared by removing all the earth between the cross-ties and refilling with concrete to the top of the ties. Upon this a 2-inch sand cushion was laid and the bricks were placed upon this. A cement curbing 4 inches wide by 20 inches deep was placed on the south side of this section, while on the north side, owing to a greater amount of traffic, a curbing 6 inches wide by 20 inches deep was laid.

Table 16.—*Analysis of bituminous filler.*[a]

Specific gravity 25°/25° C.	0.980
Melting point °C. (cube method)	108°
Penetration (No. 2 N, 5 seconds, 100 grams, 25° C.)	54°
Per cent of loss at 163° C., 5 hours (20 grams)[b]	1.15
Penetration of residue (as above)	48°
Per cent of bitumen insoluble in 86° paraffin naphtha	26.88
Per cent of fixed carbon	8.36
Per cent of bitumen soluble in CS_2, air temperature (total bitumen)	99.83
Organic matter insoluble	.09
Inorganic matter	.08
	100.00

[a] Dense, rubbery.

[b] Surface of residue somewhat drawn.

After the curbing had thoroughly set, a form reaching $5\frac{3}{4}$ inches below the top of the curb at the side of the road and $1\frac{3}{4}$ inches below at the center was pulled over the section, and all uneven places were filled with stone or cut off, until a uniform crown of $\frac{1}{2}$ inch to the foot had been obtained. Next to the curbing was then placed a board 1 inch wide and 6 inches deep, which, upon the completion of the road, was withdrawn. This space was then filled with a bituminous filler (see Table 16) to within 1 inch of the top. The remaining space was filled with sand. A 2-inch course of sand was spread over the foundation and, after this had been dragged with a wooden form to conform to the road surface, it was compacted with the light hand roller in order to obtain a uniform cushion for the brick. The roller was started at the sides, moved longitudinally to the center, and then rolled at right angles to the length of the road, after which it was rolled at an angle of 45° in both directions. This produced a firm but slightly uneven surface, which was made smooth by a light coat of screened sand. The whole surface was finally struck off to produce a sand cushion 2 inches in depth. Upon this the brick, which had been furnished by six different manufacturers, was laid with unskilled labor at right angles to the center line of the road. The brick surface was then rolled with a 2-ton tandem roller, made from a self-propelled lawn mower and carrying the greater part of the weight on the front roller. The roller was started next to the curb and gradually worked toward the center of the road, and in like manner from the other side. This operation was repeated twice, after which the road was rolled twice in both directions at an angle of 45° to its length. This process was repeated three times until the brick had become firmly set.

Wooden boxes about 30 inches wide, 14 inches deep, and 4 feet long on top, with ends sloping into the bottom at an angle of 45°, were now obtained. These boxes were set on legs of unequal length; the shortest was about 8 inches in length, and the longest, on the corner diagonally opposite, about 18 inches. Into one of these boxes was placed about two-thirds bushel of a mixture of equal parts of sand and cement. Water was then added until the resulting mortar flowed readily. Two men stood at the high end of the boxes with mortar-hoes and kept the mixture in constant motion, while a man stood on the lower side with a scoop, shoveling the grout upon the brick by dropping it suddenly from the shovel, but without throwing it. Three men with brooms and squeegees immediately worked the grout into the joints between the brick. After the brick had been covered for a distance of about 20 feet, this treatment was repeated. In about three-fourths of an hour a final coat of three parts of cement to two parts of sand, made considerably thicker than before, was applied. The surface was then squeegeed, so that a thin layer of

cement was left over the surface of the brick, and the joints were well filled. Owing to damp weather, it was unnecesary to cover the brick with sand to keep the filler moist. The road was closed to traffic for ten days, and not even the street cars were allowed to pass during that time.

On account of unskilled labor and the slow methods used in constructing the curb, the cost was exceedingly high for this kind of work. The cost of brick per square yard is averaged from the cost of each kind of brick, in connection with the area covered by each or the number used. The first 83 feet of roadway running from the car track were laid with brick costing $12.75 per thousand f. o. b. cars at the point of manufacture. The cost of the brick for the adjoining 70 feet was $12.25 per thousand and for the three different kinds of brick used on three 51-foot sections $14, $17.50, and $13.75 per thousand, respectively, f. o. b. cars at the point of manufacture. The rail bricks were figured at $20 per thousand f. o. b. cars at the point of manufacture. They were laid only on the inner side of the outer rail, and did not add very materially to the average cost per square yard. The results of tests made upon these bricks are shown in the following table. It should be noted that these tests are not complete owing to an insufficient number of bricks being left over from the work.

TABLE 17.—*Brick tests.*

Brick No.	Rattler test. Per cent of loss. Average of 2 tests.	Cross-breaking test. Modulus of rupture. Pounds per square inch. Average of 10 tests.	Crushing test. Pounds per square inch. Average of 5 tests.	Water absorbed. Per cent of dry weight. Average of 3 tests.		
				One-half hour.	Six hours.	Forty-eight hours.
2		[a] 2,464	[b] 9,218	0.16	0.27	0.57
3	14.88	1,738	5,588	.30	.66	2.22
4	15.14	2,183	4,950	.98	1.37	1.89
5	14.28	1,700	4,890	.31	.58	1.15
Rail	17.20	1,669	5,610			

[a] Average of 5 tests. [b] Average of 3 tests.

SUMMARY OF EXPERIMENTS AT ITHACA.

All of the sections were in excellent condition when last inspected on December 2, so that it is impossible to draw definite conclusions as to the relative merits of the different materials at the present time. The final results will be published in a later circular.

TABLE 18.—*Items of cost.*

EXPERIMENT NO. 10, SECTION NO. 7—KENTUCKY ROCK ASPHALT.

Length of section (feet)	300
Area of section (square yards)	533
No. 2 stone, cubic yards per square yard	0.111
Rock asphalt, cubic yards per square yard	0.041

TABLE 18.—*Items of cost*—Continued.

EXPERIMENT NO. 10, SECTION NO. 7—KENTUCKY ROCK ASPHALT—continued.

Cost of No. 2 stone on siding, per square yard (cents)	14.55
Cost of hauling and laying stone, per square yard (cents)	4.43
Cost of rock asphalt, per square yard (cents)	31.08
Cost of hauling rock asphalt, per square yard (cents)	4.71
Cost of spreading rock asphalt, per square yard (cents)	2.29
Cost of rolling, per square yard (cents)	1.88
Cost of freight on rock asphalt, per square yard (cents)	24.10
Total cost, per square yard (cents)	83.04
Total cost of entire section	$442.60

EXPERIMENT NO. 11, SECTION NO. 11—SLAG.

Length of section (feet)	200
Area of section (square yards)	355
No. 2 size stone, cubic yards per square yard	0.139
Screenings, cubic yards per square yard	0.022
Lime, pounds, per square yard	3.3
Cost of No. 2 slag, at siding, per square yard (cents)	30.28
Cost of slag screenings, at siding, per square yard (cents)	4.83
Cost of hauling and laying slag, per square yard (cents)	8.40
Cost of lime on road, per square yard (cents)	2.26
Cost of rolling, per square yard (cents)	2.79
Cost of sprinkling, per square yard (cents)	1.00
Total cost, per square yard (cents)	49.56
Total cost of entire section	$175.94

EXPERIMENT NO. 14, SECTION NO. 3—BRICK.

Length of section (feet)	306
Area of section (square yards)	526
Length of curbing (feet)	590
Sand cushion, cubic yards per square yard	0.056
Average number of bricks per square yard	40
Cost of curbing, per running foot	$1.00
Cost of bituminous filler, per running foot (cents)	3.75
Cost of sand cushion per square yard (cents)	4.08
Cost of hauling and laying brick (cents)	20.81
Cost of brick, per square yard (cents)	55.52
Cost of freight on brick, per square yard (cents)	40.20
Cost of cement filler, per square yard (cents)	8.53
Cost of rolling brick, per square yard (cents)	1.53
Miscellaneous expenses, per square yard (cents)	7.56
Cost of curbing, per square yard of road (cents)	112.50
Cost of bituminous filler, per square yard of road (cents)	4.23
Total cost of road, per square yard (cents)	254.96
Total cost of entire section	$1,341.09

TABLE 19.—*Materials and cost data of experiments at Ithaca, N. Y.*

PENETRATION METHOD.

Description.					Quantity of material.				Cost data per square yard, in cents.									Total cost.	
Experiment No.	Section No.	Binder.	Length of section (feet).	Area of section (square yards).	No. 2 stone (cubic yards per square yard).	Screenings (cubic yards per square yard).	Binder, first application (gallons per square yard).	Binder, second application (gallons per square yard).	No. 2 stone at siding.	Screenings at siding.	Hauling and laying stone.	Binder.	Hauling binder.	Heating and applying binder.	Rolling.	Miscellaneous.	Freight on binder.	Square yard (cents).	Entire section.
1	1	Refined coal tar	300	620	0.111	0.022	1.46	0.56	14.55	2.91	5.27	12.41	2.84	2.02	0.92	1.00	4.00	45.92	$284.70
5	5	Refined semiasphaltic oil	300	533	.111	.022	1.50	....	14.55	2.91	5.27	17.25	2.92	1.50	.92	1.00	3.00	49.32	262.88
6	6	Semisolid refined semiasphaltic oil	300	533	.111	.022	1.64	....	14.55	2.91	5.27	11.48	3.19	1.64	.92	1.00	2.36	43.32	230.90
7	8	Refined water-gas tar	300	533	.111	.022	1.88	....	14.55	2.91	5.27	13.16	3.65	1.88	.92	1.00	3.61	46.95	250.24
8	9	Refined semi-asphaltic oil	300	533	.111	.022	2.06	....	14.55	2.91	5.27	14.42	4.01	2.06	.92	1.00	7.16	52.30	278.76
9	10	Refined water-gas tar (slag)	100	178	.138	.022	1.47	....	30.28	4.83	8.40	10.29	2.86	1.47	.92	1.00	2.82	62.87	111.91

MIXING METHOD.

Description.					Quantity of material.					Cost data per square yard, in cents.										Total cost.	
Experiment No.	Section No.	Binder.	Length of section (feet).	Area of section (square yards).	No. 2 stone (cubic yards per square yard).	Mixed stone (cubic yards per square yard).	Screenings (cubic yards per square yard).	Binder in mixture (gallons per square yard).	Binder used in paint coat (gallons per square yard).	No. 2 stone at siding.	Screenings at siding.	Hauling and laying stone.	Binder.	Hauling binder.	Preparing and laying mixture.	Heating and applying paint coat.	Rolling.	Miscellaneous.	Freight on binder.	Square yards (cents).	Entire section.
2	2	Refined coal tar	300	622	0.042	0.069	0.022	0.92	0.44	14.55	2.91	5.27	11.56	2.65	10.32	0.44	0.92	4.52	2.88	56.02	$348.44
3	4	Artificial oil asphalt	275	489	.042	.069	.022	.92	....	14.55	2.91	5.27	9.28	1.79	10.32	......	.92	4.52	9.06	58.62	286.65
4	12	.....do	260	463	....	.069	.022	.92	.98	9.09	2.91	3.29	14.25	3.70	18.59	.98	.92	4.52	2.64	60.89	281.92

CONCRETE.

Description.					Quantity of material.				Cost data per square yard, in cents.										Total cost.	
Experiment No.	Section No.	Binder.	Length of section (feet).	Area of section (square yards).	Coarse aggregate (cubic yards per square yard).	Sand (cubic yards per square yard).	Cement (cubic yards per square yard).	Bitumen (gallons per square yard).	Coarse aggregate at mixer.	Sand at mixer.	Cement at mixer.	Mixing and laying concrete.	Bitumen.	Hauling bitumen.	Heating and applying bitumen.	Screenings on road.	Freight on bitumen.	Miscellaneous.	Square yard (cents).	Entire section.
12a	15	Cement concrete	500	889	0.140	0.052	0.026	......	23.10	3.91	29.30	17.28	......	......	......	......	......	1.18	74.77	$664.70
12b	14	Bitumen coated, cement concrete	30	53	.140	.052	.026	0.84	23.10	3.91	29.30	17.28	6.30	1.64	0.84	1.00	1.17	1.18	85.72	45.43
13	13	Ash cement concrete	35	62	.138	.045	.017	......	4.27	3.38	19.42	20.16	......	......	......	......	......	1.18	48.41	30.01

SUPPLEMENTARY REPORT OF EXPERIMENTS MADE AT NEWTON, MASS., IN 1908, WITH ASPHALTIC PREPARATIONS, TAR PREPARATIONS, RESIDUAL OIL, AND MOLASSES-OIL-LIME.

A full report of these experiments may be found in Circular No. 90. Seven experiments were made with an asphaltic preparation, one with a residual oil, two with a refined water-gas tar, and one with a molasses-oil-lime mixture. This work consisted in resurfacing an old macadam road according to the mixing method, using the various materials as binders. The sections were last inspected July 22, 1909, about eleven months after being laid.

Experiments Nos. 1, 2, 3, 4, 5, 6, and 7—asphaltic preparation.—At the time of inspection there was considerable difference in the appearance of these sections. Section No. 1, in which a mineral aggregate containing practically no fine material smaller than one-fourth inch in diameter had been used, had raveled in places and had been patched with a refined coal tar under the direction of the street commissioner of Newton. Section No. 2, in which a mineral aggregate containing more fine material had been used, was in better condition, but had been patched in a number of weak places with the coal-tar preparation above mentioned. Section No. 3, in which the mineral aggregate held a still greater amount of material smaller than one-fourth inch in diameter, was in much better condition and only one patch had been required. Section No. 4, which had been constructed in a manner similar to No. 3, except that instead of stone screenings a light coat of tarred sand had been employed as a surface dressing, had not required patching, but the surface was in rather poor condition. In all of the first four experiments only 0.54 gallon of asphaltic preparation per square yard had been used. In experiments Nos. 5 and 6 a flush coat of bitumen had been applied in addition to this. The asphaltic preparation was used for this purpose in No. 5 and a refined coal tar in No. 6. These two sections, together with No. 7, in which 0.71 gallon per square yard of the asphaltic preparation had been used, were in first-class condition when inspected.

Experiment No. 8—residual oil.—Section No. 8, bound with a residual oil, was just beginning to pick up under traffic and the oil showed a lack of adhesiveness.

Experiments Nos. 9 and 10—refined water-gas tar.—Sections Nos. 9 and 10, in which a refined water-gas tar was employed as a binder, were both in excellent condition; No. 10 indeed appeared better than any of the other sections. In No. 9, 0.81 gallon per square yard of the water-gas tar was consumed and the surface was coated with stone screenings, while in No. 10 an application of sand mixed with a refined coal tar was used as a surface dressing.

Experiment No. 11—molasses-oil-lime.—The molasses-oil-lime work was in very good condition, except at a rather sharp curve where the surface had just started to pick up under traffic.

SUPPLEMENTARY REPORT OF EXPERIMENT MADE AT INDEPENDENCE, KANS., IN 1908, WITH AN ARTIFICIAL ASPHALT IN THE CONSTRUCTION OF AN EARTH-ASPHALT ROAD.

The original report of this experiment may be found in Circular No. 90. On February 19, 1910, the road was inspected, and, while the conditions for making an intelligent inspection were unfavorable, since the road was frozen and partially covered with snow, the following results were reported:

The appearance of the road in general was similar to that of other dirt roads in the near vicinity, except that it did not show the deep ruts noticeable on the latter, although the traffic over both is similar. This shows that during the winter the mud had not been as deep as on the ordinary dirt roads. The only attention that it has received since being built is that it was dragged once in February, 1909.

For the length of two blocks the road has a grade of nearly 5 per cent and had previously washed badly, but now shows but little, if any, effects of last year's rains. Residents along the road state that during rainy weather the road is quite muddy on top, but that there is no deep mud and that the road dries out much sooner than the neighboring dirt roads. In summer, however, this road is a little soft under heavy loads.

The conclusions to be drawn are that the asphalt mixed with the earth renders it fairly impervious to water; that it acts sufficiently well as a binder to prevent the washing of ruts on grades; that an asphalt having a melting point higher than that used should be employed, if a satisfactory road is to be had in the summer; that such an asphalt can not be spread upon and mixed with earth satisfactorily unless the earth is previously heated; that such a road is practically dustless save for dirt that may be carried upon it; and that, to prevent its being muddy just after a rain, 2 to 3 inches of from ¾-inch to 2-inch stone should be worked into the top.

SUPPLEMENTARY REPORT OF EXPERIMENTS MADE AT GARDEN CITY, DODGE CITY, BUCKLIN, AND FORD, KANS., IN 1908, WITH SAND-CLAY.

The original report of these experiments may be found in Circular No. 90. They were made with a view to determine the suitability of sand-clay construction to meet varying conditions encountered in the Middle West.

Experiment at Garden City.—In this experiment a local gypsum-clay was mixed with the natural sandy soil. The road was inspected one year after completion and was found to be as hard and firm as macadam. The people living in the vicinity of this work were so well pleased with the results that during the past year 7 miles more of sand-clay road were constructed at their instigation.

Experiment at Dodge City.—In the work at Dodge City a clay silt obtained from an old irrigation ditch was mixed with a sandy soil similar to that encountered at Garden City. When inspected one year after completion the road was in excellent condition. Although previously but little used, it has been converted into one of the most heavily traveled roads leading into Dodge City. Land values along this road have increased, and farmers who were formerly considering the advisability of selling their farms and going where the roads were better are now well satisfied to remain.

Experiment at Bucklin.—In this experiment the general plan of construction was identical with that used at Dodge City, except that a buckshot-clay was mixed with the sandy soil. When inspected a year later the road, while not smooth, had not rutted. The inspection was made after a heavy rain, during which the road had softened to such an extent that the surface picked up under traffic. This indicated merely an insufficiency of sand on the surface and the trouble was easily remedied.

Experiment at Ford.—In this experiment a short section of sandy road, forming the south approach to a bridge crossing the Arkansas River, was graded and a sedimentary clay added. The work was done under very unfavorable conditions, which made it impossible to mix the sand and clay in an altogether satisfactory manner. When inspected one year after completion the surface was covered with about 1 inch of mud, showing that more sand was needed; otherwise the road was in good condition.

SUPPLEMENTARY REPORT OF EXPERIMENTS MADE AT WAYLAND, MASS., IN 1907, WITH CRUDE TAR, TAR PREPARATIONS, AND OIL EMULSIONS.

These experiments are described in Circular No. 89, published in March, 1908, and in a report of an inspection made in September, 1908, published in Circular No. 90. By 1909 the entire road needed to be treated again, and during that year a surface application of tar was made with an English spraying machine, under the supervision of the Massachusetts State Highway Commission. This road is subjected to such heavy mixed traffic that annual surface treatments will probably be required in order to keep it in good condition.

SUPPLEMENTARY REPORT ON AN EXPERIMENT MADE AT BOWLING GREEN, KY., IN 1907, WITH KENTUCKY ROCK ASPHALT.

A full report of this experiment may be found in Circular No. 89, and the results of an inspection made in January, 1909, are to be found in Circular No. 90.

This road was again inspected during the latter part of May, 1909, and the following report made. A heavy rain had been falling for some hours before the inspection was made, and there was more or less soft, sticky mud on the roads adjoining the experimental road.

The surface of the rock asphalt was clean, smooth, and compact, with no ruts, and had much the same appearance as a first-class asphalt city street. The thin surface course of rock asphalt has worn down in a few spots to the crushed stone, but the individual crushed stones were tightly bound together and not a single loose stone was found.

SUPPLEMENTARY REPORT ON EXPERIMENTS MADE AT JACKSON, TENN., IN 1905, WITH TARS AND OILS.

The original report of these experiments may be found in Circular No. 47, published May, 1906, and reports of the condition of the sections when inspected in February, 1908, and January, 1909, are to be found in Circulars Nos. 89 and 90. When last inspected, on December 2, 1909, the following results were reported:

Tar experiments.—An inspection made December 2, 1909, of the streets of Jackson, Tenn., which were treated with coke-oven tar, shows that where a second application of tar was applied one year after the first the surface was smooth and even, and that there was only an occasional break at intervals of about 20 feet, with the exception of a strip averaging about 20 feet wide down the center of the street where traffic is heaviest and droppings from unimproved streets accumulate. Very little trace of tar could be found in this center strip.

On the streets which were treated with only one coat of tar the deterioration is much more apparent. In the center of the streets no trace of tar can be found, and on the sides, for a distance of about 25 feet from the gutters, patches of tar coating, varying in size from 6 inches to 6 feet in diameter could be seen at intervals of a few feet. The short section which was spiked up and where the tar was incorporated in the macadam showed that the crown has almost entirely disappeared, owing to a softening of the binder during the summer months. Detritus accumulates on this section to such an extent that, from a casual inspection, no tar could be noticed. When a part of the section was cut out, however, the tar could be plainly seen in the voids between the particles of stone.

It might be added that the streets have been badly neglected since treatment. A third application of tar, applied last summer, would have made these roads almost as good as they were after the first application, and even yet it is not too late to save the city hundreds of dollars.

Oil experiments.—No trace of oil was found on the city streets which had been treated. On the section of country road treated with residual oil a strip about 3 feet wide on either side of wheel tracks showed distinct traces of oil, which was still beneficial in preventing side washes.

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Issued January 27, 1911.

U. S. DEPARTMENT OF AGRICULTURE,

OFFICE OF PUBLIC ROADS—Circular No. 93.

LOGAN WALLER PAGE, Director.

BITUMENS AND THEIR ESSENTIAL CONSTITUENTS FOR ROAD CONSTRUCTION AND MAINTENANCE.

BY

PRÉVOST HUBBARD,

CHEMIST, OFFICE OF PUBLIC ROADS.

WASHINGTON:

GOVERNMENT PRINTING OFFICE.

1911.

LETTER OF TRANSMITTAL.

U. S. Department of Agriculture,
Office of Public Roads,
Washington, D. C., December 5, 1910.

Sir: I have the honor to transmit herewith the manuscript of a circular by Mr. Prévost Hubbard, chemist in this office, entitled "Bitumens and Their Essential Constituents for Road Construction and Maintenance." This publication presents in condensed form a description and discussion of various bituminous materials at present in use in road construction and maintenance. It should be of great service in clearing up a very general misunderstanding concerning the actual and comparative value of bituminous road materials, and also the meaning of certain terms. I respectfully request that it be issued as Circular 93 of this office. In view of the newness of the subject and lack of complete data, some of the statements made may in the future require modification. This circular will therefore be revised from time to time in order to keep it abreast with the latest information obtainable.

Respectfully,

Logan Waller Page,
Director.

Hon. James Wilson,
Secretary of Agriculture.

BITUMENS AND THEIR ESSENTIAL CONSTITUENTS FOR ROAD CONSTRUCTION AND MAINTENANCE.

So much confusion exists among road engineers and others interested in bituminous road binders concerning the meaning of certain terms as applied to these materials that it has seemed advisable to present in brief form the definitions of such terms as at present used by the United States Office of Public Roads. It should be understood, however, that these definitions are at present more or less arbitrary, owing to wide differences of opinion held by those who are considered authorities on the subject of bitumens. Notwithstanding these facts, it is hoped that this circular will furnish highway engineers and other interested persons with a foundation for acquiring and systematically classifying further information along the lines herein indicated. To aid them in this matter a brief discussion of the value of the various materials used in road construction has been given in addition to the definitions.

Acid Sludge.—A mixture of sulphonated hydrocarbons resulting from the treatment of bitumens with sulphuric acid; usually a waste or by-product obtained in this manner from the purification of tar and oil distillates. When sufficiently concentrated these sulphonated products become viscous and gummy. They are readily attacked by water and are therefore unsuitable for use as enduring road binders.

Anthracene.—A waxy crystalline hydrocarbon having the chemical formula $C_{14}H_{10}$, found in tars, principally coal tars which have been produced at high temperatures. Anthracene is believed to be of no practical value in road binders.

Artificial Asphalt.—See Asphalts and Oil Asphalts.

Artificial Bitumens.—Hydrocarbon distillates and residues produced by the partial or fractional distillation of bitumens, and hydrocarbon distillates produced by the destructive distillation of bitumens, pyrobitumens, and other organic materials, such as wood, bone, etc. Native bitumens which have been treated merely for the removal of water and extraneous organic and inorganic materials should not be classed as artificial products, but as refined native bitumens.

Asphalts.—Solid or semisolid native bitumens, consisting of a mixture of hydrocarbons of complex structure, largely cyclic and bridge compounds, together with a small proportion of their sulphur and nitrogen derivatives, but free from any appreciable amount of solid

paraffins, melting[1] upon the application of heat and evidently produced by nature from petroleums containing little or no solid paraffins. Solid or semisolid residues produced from probably similar oils by artificial processes are sometimes called asphalts, but should more properly be termed oil asphalts. The more common types of native asphalts are known by the name of the locality in which they occur, such as Trinidad, Bermudez, Maracaibo, Cuban, California, etc. Native asphalts with few exceptions contain water, extraneous organic or vegetable matter, and inorganic matter, such as clay, sand, etc. A large proportion of these impurities is removed by a rough refining process without otherwise changing the character of the asphalt.

Native asphalts are usually too hard to be used as road binders without first fluxing them with a heavy petroleum residuum and thus producing an asphaltic cement. Artificial asphalts are, as a rule, brought to suitable consistency during the process of manufacture.

Asphaltenes.—A term commonly applied to those hydrocarbons in petroleums, petroleum products, malthas, asphaltic cements, and solid native bitumens which are soluble in carbon bisulphide but insoluble in paraffin naphtha. As a rule paraffin naphthas of different specific gravities and boiling points dissolve different amounts of hydrocarbons in a given bitumen, and the heavier the naphtha and the higher its boiling point the greater is its solvent action. It is evident, therefore, that the percentage of asphaltenes will vary with the gravity and boiling point of the naphtha, and for this reason it would seem well to substitute for the term asphaltenes, "bitumen insoluble in paraffin naphtha," with a statement of the gravity of the naphtha used and the temperatures between which it boils. The presence of naphtha insoluble hydrocarbons is supposed to give body to the product in which they occur and to be accountable to a great extent for its binding value. They show no binding value, since many of them are hard and brittle, but they produce adhesive mixtures when fluxed with certain heavy oils. As a rule, for a given type of bitumen hardness increases with the percentage of bitumen insoluble in a given naphtha. The so-called asphaltenes are not found to any extent in native bitumens with a paraffin base, but occur principally in asphalts, malthas, asphaltic petroleums, and in blown petroleum residues. They vary chemically and physically with the product in which they occur, and, therefore, do not represent definite chemical compounds.

Asphaltic Petroleums.—Asphaltic petroleums, or asphaltic oils, are petroleums containing an asphaltic base—i. e., they are capable of producing residues very similar to native asphalts if evaporated or distilled down to the consistency of such asphalts. They contain little

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[1] See Bitumens.

or no solid paraffins and are thus differentiated from paraffin petroleums. Native asphalts are probably produced from such oils by natural processes.

Asphaltic Cement.—The term asphaltic cement was originally applied to a product obtained by fluxing an asphalt with a sufficient quantity of heavy residual oil or flux to produce a binder of suitable consistency for paving purposes. In its broadest sense it may be applied to all semisolid bitumens of an asphaltic nature which are of suitable consistency for use as binders in street or road construction, whether prepared by fluxing a solid native or artificial bitumen or by reducing an asphaltic or semiasphaltic petroleum by distillation or other process.

Baumé Gravity.—An arbitrary scale of specific gravity or density of liquids, usually expressed as degrees Baumé or ° B. This scale is commonly used in connection with oil products. For liquids lighter than water the scale begins at 10° B., which represents the specific gravity of water, or 1.0000. As the Baumé degrees increase the specific gravity decreases. The following formulæ are used in converting Baumé degrees for liquids lighter than water into direct specific gravity and vice versa:

$$\text{Sp. gr.} = \frac{140}{130 + {}^\circ\text{B}} \text{ at } 17.5^\circ \text{ C.}$$

$$^\circ\text{B} = \frac{140}{\text{Sp. gr.}} - 130 \text{ at } 17.5^\circ \text{ C.}$$

For liquids heavier than water the scale begins at 0° B., which represents the specific gravity of water, or 1.0000. In this scale the degrees Baumé increase with the specific gravity. The following formulæ are used in converting Baumé degrees for liquids heavier than water into direct specific gravity and vice versa:

$$\text{Sp. gr.} = \frac{145}{145 - {}^\circ\text{B}} \text{ at } 15.5^\circ \text{ C.}$$

$$^\circ\text{B} = 145 - \frac{145}{\text{Sp. gr.}} \text{ at } 15.5^\circ \text{ C.}$$

Benzol.—A volatile colorless fluid hydrocarbon of characteristic odor having the chemical formula C_6H_6. It occurs mainly in crude coal tars and water-gas tars, and boils at 80.4° C., so that it is removed in the first fraction when these tars are subjected to the process of distillation. Benzol is an active solvent for most bitumens. It is sometimes called benzene, but should not be confused with benzine, which is the term applied to the lighter and more volatile fractions of petroleum.

Bitumen.—Bitumens are mixtures of native or pyrogenetic hydrocarbons and their derivatives, which may be gases, liquids, viscous liquids, or solids. If solids, they melt more or less readily upon the application of heat and are soluble in carbon bisulphide, chloroform, and similar solvents. They may be divided into two main classes—(1) native bitumens and (2) artificial bitumens. Bitumens, being mixtures of hydrocarbons, can have no melting point, although this term is often used to denote the temperature at which they soften sufficiently to flow.

Bituminous.—A term applied not only to materials or objects which contain bitumen, such as bituminous rock, bituminous macadam, etc., but also to certain pyro-bitumens, such as bituminous coal, which give rise to the formation of bitumens upon being subjected to the process of destructive distillation.

Blown petroleum.—Blown petroleums, which are often called blown oils, are petroleum residuums through which a jet of air has been passed during or just after distillation. The blowing process causes certain chemical reactions of a complicated nature to take place and results in thickening or increasing the consistency of the oil to an extent depending upon its temperature and the amount of blowing which it receives. Semisolid and solid products are thus often formed from fluid residuums. If the oil is asphaltic or semiasphaltic in nature, asphaltic cements may be produced in this manner. Blown oils are characteristically short or nonductile when semisolid, although they may possess considerable binding value if not originally of a paraffin nature. Blowing an oil usually increases its percentage of hydrocarbons insoluble in any given paraffin naphtha.

Carbenes.—A term commonly applied to those hydrocarbons in petroleum, petroleum products, malthas, asphaltic cements, and solid native bitumens which are soluble in carbon bisulphide but insoluble in carbon tetrachloride. The presence of an appreciable amount of these hydrocarbons indicates that the material in which they occur has been subjected to unnecessarily high temperatures. Cracked oil residuums show an increase in carbenes in proportion to the extent of cracking and the formation of these products is evidently a near step to coking. But little is known of their effect upon the value of a bitumen for road construction, but they are generally looked upon with suspicion and, in certain specifications for asphaltic cements, their presence has been limited to a low percentage.

Carbon Bisulphide.—This substance, sometimes called carbon disulphide, is a volatile and extremely inflammable compound of carbon and sulphur, boiling at 47° C. and having the chemical formula CS_2. Pure carbon bisulphide is a colorless mobile liquid having an ethereal odor. It is one of the most active solvents for bitumens

and is commonly employed for this purpose in the determination of total bitumen.

Carbon Tetrachloride.—A volatile noninflammable compound of carbon and chlorine, boiling at 76° C. It is a colorless mobile liquid with an odor similar to that of chloroform, to which it is closely related, and has the chemical formula CCl_4. It is an excellent solvent for bitumens, but is not usually as powerful as carbon bisulphide. It is employed in bitumen analysis for the determination of carbenes or hydrocarbons soluble in carbon bisulphide but insoluble in carbon tetrachloride.

Coal Tar.—A mixture of hydrocarbon distillates, mostly unsaturated ring compounds, produced in the destructive distillation of coal. Crude coal tar is a black, more or less viscid fluid having a gassy odor and varying in specific gravity from 1.10 to 1.25 and sometimes higher. It always contains a certain amount of ammoniacal water which makes it unsuitable for use as a road binder. When reduced to proper consistency by distillation, coal tar makes an excellent bituminous road binder, providing it does not carry too high percentages of free carbon and naphthalene. The composition of coal tar varies according to the coal from which it is produced and the method of distillation. Tars produced at high temperatures contain a large amount of free carbon and usually run high in naphthalene, while those produced at low temperatures carry less free carbon and as a rule less naphthalene. Low temperature coal tars are therefore most suitable for the preparation of road binders.[1]

Coke-Oven Tar.—Coal tar produced from by-product coke ovens in the manufacture of coke from bituminous coal. This process of coke manufacture is essentially the same as that of coal gas. Larger charges of coal are, however, carbonized in the former, and as a rule carbonization is conducted at a lower temperature than in the manufacture of coal gas. The resulting tar therefore contains a smaller amount of free carbon, averaging from 3 to 10 per cent, and is better suited for the preparation of road binders than most gas-house coal tars.

Cracked Oil.—The term cracked oil, as applied to road binders, refers to petroleum residuums which have been overheated in the process of manufacture. Overheating causes a breaking down of certain constituents of the oil, which results first in the formation of carbenes and later of coke or free carbon. Badly cracked residuums are believed to be inferior road binders.

Cracking.—The process of breaking down a hydrocarbon molecule by the application of heat. This may result either in the formation of other hydrocarbon molecules, at least one of which is unsaturated

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[1] See Refined tar.

and shows a higher ratio of carbon to hydrogen than the original molecule, or else in the disruption of the molecule into its elements, hydrogen and carbon. In the latter case the process is said to be destructive. The more volatile and chemically stable hydrocarbons can be cracked only at temperatures above their boiling points. In the distillation of oils this is accomplished by causing condensation to take place in the still and allowing the condensed oils to fall back into the residue, the temperature of which is considerably higher than their boiling points. In carbureted water-gas manufacture, oils are cracked by vaporizing them at a much higher temperature than their boiling points. The heavier oils will, however, crack at temperatures below their normal boiling points, and this is particularly true of asphaltic oils, which have to be distilled very carefully, sometimes under reduced pressure, in order to produce residuums which are not cracked.

Cut-Back Products.—Petroleum or tar residuums which are cut back, or fluxed, to the desired consistency with a distillate. Volatile distillates are employed for this purpose in the preparation of road binders, when it is desired to have the binder increase in consistency or become harder after application. In such cases a residuum of proper consistency for a road binder is cut back merely for the purpose of facilitating application.

Dead Oils.—Heavy oils distilled from tars at between 170° and 270° C. with a density greater than water. These oils, if free from naphthalene, serve as an excellent flux in the preparation of cut-back road binders from tar pitches, which are too brittle for this purpose.

Destructive Distillation.—A process of distilling organic materials in which the identity of the material distilled is destroyed, resulting in the formation of tarry distillates and a coke residue.

Dehydrated Tar.—Crude tar from which all water has been removed by distillation and mechanical contrivances known as separators.

Emulsions.—Oily substances made miscible with water through the action of a saponifying agent or soap. Petroleums and tars may be emulsified by this means and such emulsions, if properly prepared from good materials, are often serviceable in the treatment of roads. The majority of road emulsions can be considered only as dust palliatives and temporary binders.

Fixed Carbon.—The residual coke obtained upon burning hydrocarbon products in a covered vessel in the absence of free oxygen, according to an arbitrary method. As applied to bituminous road materials, the determination of fixed carbon would seem to be of value in connection with petroleum and asphaltic products only. Paraffin hydrocarbons produce little or no fixed carbon, while those of asphaltic character show a very considerable amount, depending upon the percentage of asphaltic compounds present and the consistency of

the material. The fixed carbon determination therefore indicates the mechanical stability and body of such materials. It is not, however, an extremely accurate determination and should not be too strongly relied upon. Since fixed carbon is a product formed by ignition, it should not be confused with free carbon, which is a material already existing in suspension. The presence of any considerable quantity of free carbon vitiates a fixed carbon determination.

Flux.—As applied to road binders, this term covers fluid oils and tars which are incorporated with asphalts and semisolid or solid oil and tar residuums for the purpose of reducing their consistency. Fluid petroleum residuums are commonly employed as fluxes in the preparation of asphaltic cements. A good flux produces an absolutely homogeneous bituminous mixture. Both petroleum and tar fluxes will produce such mixtures with native and artificial asphalts, but most fluid petroleum products will not flux tar pitches satisfactorily.

Free Carbon.—Organic matter in tars which is insoluble in carbon bisulphide. This material is an inert black powder, which is held in suspension by the tar proper, and probably consists, not only of free carbon, but also of hydrocarbons extremely rich in carbon. It has no binding value and serves no useful purpose in a road binder other than to act as a filler. It gives the tar in which it occurs a false consistency, reduces the binding capacity of the tar, and probably interferes with its penetration into and absorption by the road stone or road surface. The maximum allowable limit of free carbon in road binders would seem to be about 20 per cent.

Gas-House Coal Tar.[1]—Coal tar produced as a by-product in the manufacture of illuminating gas from coal. The modern gas-house coal tar is usually produced at high temperatures and therefore carries a percentage of free carbon varying from 20 to 30 per cent and higher. Unless it is produced at low or medium temperatures and contains less than 20 per cent free carbon, it is not well suited for the preparation of a dust palliative or road binder by direct distillation. High-carbon tars may, however, be combined with low-carbon tars in such proportion as to produce, when distilled to proper consistency, excellent road binders carrying less than 20 per cent free carbon.

Gilsonite.—A very pure solid native bitumen possessing many of the characteristics of asphalt. It differs from most of the native asphalts by being more brittle, having a higher melting or softening point, and being much less soluble in 86° B. paraffin naphtha. When fluxed with certain petroleum residuums it produces excellent asphaltic cements. In the preparation of road binders it is extensively used for the purpose of reinforcing blown oils, with which it combines to

[1] See Coal tar.

form rubbery semisolid mixtures. Such preparations are sometimes termed mineral rubber.

Grahamite.—A pure solid native bitumen, black and brittle, which does not melt readily, but intumesces at high temperatures. It is differentiated from gilsonite and the native asphalts by the fact that it is almost insoluble in paraffin naphtha. It has been produced at high temperatures, as evidenced by the percentage of carbenes which it contains, and some varieties closely approach the pyrobitumens in characteristics. It has been used to some extent in the preparation of asphaltic cements, but up to the present has been little used in the manufacture of road binders.

High-Carbon Tars.—Tars containing a high percentage of free carbon—above 20 per cent. High-carbon tars are produced at high temperatures during the destructive distillation of coal and are of inferior quality for use as dust palliatives and road binders.

Hydrocarbons.—Chemical compounds composed of the elements hydrogen and carbon. There is practically an unlimited number of such compounds, which vary greatly in physical and chemical characteristics. Complex mixtures of hydrocarbons constitute by far the greater proportion of all bitumens.

Low-Carbon Tars.—Tars containing a low percentage of free carbon—less than 10 per cent. Low-carbon tars are produced at comparatively low temperatures during the destructive distillation of coal, and also by cracking oil vapors during the manufacture of carbureted water gas. As a rule they are more suitable than high-carbon tars for use as dust palliatives and road binders, or for the preparation of such substances.

Malthas.—Malthas are very viscous semiasphaltic or asphaltic native bitumens holding an intermediate position between the petroleums of an asphaltic nature and the native asphalts. As a rule they possess excellent binding properties. They constitute the binding material of many bituminous rocks or rock asphalts, and in this capacity often serve as valuable road binders. Many malthas have a tendency to harden rapidly when exposed to atmospheric conditions, and this property, while accountable for an increase in binding value, makes them unsuitable for use as a flux in the preparation of asphaltic cements.

Malthenes.—A term commonly applied to those hydrocarbons in petroleum, petroleum products, malthas, asphaltic cements, and solid native bitumens soluble in both carbon bisulphide and paraffin naphtha, but not readily volatile at temperatures lower than 163° C. (325° F.). This class of hydrocarbons serves as a valuable permanent fluxing medium for the so-called asphaltenes or naphtha insoluble bitumen in asphaltic cements, giving the cement any desired degree of softness when present in the right amount. It is evident, therefore, that the consistency of asphaltic bitumens, and particularly stable

asphaltic cements, is largely dependent upon the relative proportion of naphtha soluble and naphtha insoluble hydrocarbons. The same objection to the use of the term "asphaltenes"[1] applies to the use of the term "malthenes."

Mineral Rubber.—A term sometimes applied to artificial bitumens of rubbery consistency, usually composed of a mixture of gilsonite and blown petroleum residuum.

Naphthas.—Mixtures of hydrocarbons of low boiling points occurring rarely in nature, commonly obtained from the fractional distillation of certain bitumens. When this term is applied to low-boiling coal-tar distillates, it is usually prefixed by the words "coal tar." The word "naphtha" by itself is generally applied to low-boiling petroleum products. Different grades of naphtha are differentiated not only by their boiling points but also by their specific gravities, which are commonly given in Baumé degrees. Those of very low boiling points and specific gravities are called petrolic ethers. Naphthas vary not only in the two properties above mentioned but also with the type of petroleum from which they are obtained. Those derived from paraffin petroleums are quite different chemically from naphthas obtained from asphaltic petroleums. The former are much less powerful solvents for asphaltic substances than the latter. Paraffin naphtha is used as a solvent for the separation of certain classes of hydrocarbons in asphaltic substances.

Naphthalene.—A solid crystalline highly volatile hydrocarbon occurring principally in coal tars and having the chemical formula $C_{10}H_8$. Its presence in excessive quantities in road tars is believed to be detrimental, as it possesses no binding value and gradually volatilizes from the tar, leaving it hard and brittle.

Native Bitumens.—Mixtures of hydrocarbons occurring in nature, which may be gases, liquids, viscous liquids, or solids, but if solid melting[2] more or less readily upon the application of heat and dissolving in carbon bisulphide, chloroform, and similar solvents. The native bitumens that are of use as road materials are petroleums, malthas, asphalts, and other solid products such as gilsonite and grahamite. Native bitumens often contain impurities such as water, inorganic matter in the form of clay, silt, sand, etc., and extraneous organic or vegetable matter.

Oil Asphalts.—Artificial oil pitches or asphaltic cements produced as a residuum in the distillation of semiasphaltic and asphaltic petroleum. Many of these products are blown and are therefore known as blown oils.

Oil Pitches.—More or less hard oil asphalts.

Oil Tars.[3]—Mixtures of hydrocarbon distillates, mostly unsaturated ring compounds, produced in the cracking of oil vapors at high tem-

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[1] See Asphaltenes. [2] See Bitumens. [3] See Water-gas tar.

peratures. Oil tars are usually by-products of the manufacture of oil gas or carbureted water gas.

Paraffin Naphthas.—Naphthas consisting of a mixture of light volatile hydrocarbons of the paraffin series, ordinarily obtained as light distillates of paraffin petroleum.

Paraffin Petroleum.—Petroleum the base of which is composed principally of the paraffin or open-chain series of hydrocarbons; it is thus differentiated from asphaltic petroleums which are composed largely of cyclic or ring hydrocarbons. Paraffin petroleums and the unaltered residues produced by their distillation are of inferior value as dust palliatives and road binders.

Paraffin Scale.—Solid paraffins recovered by distillation and precipitation of the distillates of petroleum and similar materials. The percentage of paraffine in bitumen is usually determined in this manner.

Paraffine.—The term paraffine covers a number of greasy crystalline hydrocarbons of the paraffin series occurring as dissolved wax in certain classes of petroleum. When these products are recovered from petroleum, they constitute the commercial product paraffine. Paraffine is believed to be detrimental to road binders in which it occurs, and it is certain that its presence in excessive amounts indicates inferiority in the binding value of the material. It is probable, however, that heavy liquid hydrocarbons of the same chemical series as solid paraffine exert a much more injurious effect.

Petrolenes.—An ambiguous term sometimes applied to those hydrocarbons described under malthenes, which are soluble in carbon bisulphide but insoluble in paraffin naphtha, and sometimes to hydrocarbons in petroleum and petroleum products volatile at or below 163° C. (325° F.). Owing to misconceptions which may occur, it would seem advisable to eliminate the use of this term.

Petroleums.—Petroleums, or mineral oils, are fluid native bitumens of variable composition, depending largely upon the locality in which they occur. There are three general types of petroleum found in the United States: (1) Paraffin petroleums, (2) semiasphaltic petroleums, and (3) asphaltic petroleums. Paraffin petroleums occur mainly in the eastern part of the United States and are typified by the Pennsylvania oils. The semiasphaltic variety occurs in the southern and middle western parts of the United States. Texas is one of the main sources of this type. Asphaltic petroleums occur in the western part of the United States, particularly in California. Petroleums, if of semiasphaltic or asphaltic character, may make excellent dust palliatives and road binders when properly treated.

Petrolic Ethers.—Very light volatile naphthas obtained from petroleum.

Pitches.—Semisolid or solid residues produced in the evaporation or distillation of bitumens. This word is often prefixed by the name

of the material from which it is derived, such as oil pitch, coal-tar pitch, etc. As a rule the term pitch is confined to the harder residuums, most of which are too hard for use as road binders unless fluxed with a more fluid product.

Pyrobitumens.—Mineral organic substances which are but slightly acted upon by the solvents for the bitumens, but which, upon being subjected to destructive distillation, give rise to the formation of bitumens. Pyrobitumens are derived in nature both from bitumens and direct metamorphosis of vegetable matter. Among the former class may be mentioned Albertite and Wurtzilite, and among the latter, peat, lignite, and bituminous coal.

Pyrogenetic.—Originating from the action of heat. Coal tar is thus a pyrogenetic bitumen.

Reduced Petroleums or Reduced Oils.—Residual oils produced from crude petroleum by the removal of water and the more volatile oil constituents, without chemically altering the base by cracking or other means. These residues are often made by distilling the crude oil under reduced pressure. Such products are of little value for road treatment unless formed from semiasphaltic or asphaltic oils.

Refined Tar.—A more or less viscous tar which is produced by evaporation or distillation of crude tar until the residue is of the desired consistency. This term also includes blown tars and cut-back products produced by fluxing tar pitches with volatile or non-volatile distillates. Refined tars are of value both as dust palliatives and as road binders in the treatment of macadam roads. Their binding value is proportional to their hardness within certain limits.

Residual Petroleums or Residual Oils.—Heavy viscous residues produced by the evaporation or distillation of crude petroleum until at least all of the burning oils have been removed and often some of the heavier distillates as well. Residual oils grade into the artificial asphalts and oil pitches as their hardness and viscosity increase. The more fluid products, if obtained from semiasphaltic or asphaltic petroleums, serve as excellent dust palliatives and semipermanent road binders for the surface treatment of roads. The more viscous products are often suitable for the surface treatment of roads if applied hot, but are seldom of value in road construction unless produced from semiasphaltic or asphaltic oils.

Residual Tars.—Heavy viscous residues produced by the evaporation or distillation of crude tar until all of the light oils have been removed. Residual tars grade into the tar pitches as their hardness and viscosity increase. If they do not contain an excess of free carbon, they are as a rule well adapted for use as binders in the construction of macadam roads.

Rock Asphalt or Bituminous Rock.—A term applied to a great variety of sandstones and limestones more or less impregnated with maltha.

Deposits of such material are widely distributed over the United States and vary from rock which is friable and wholly dependent upon the bitumen to hold the mineral fragments together to solid rock having merely its interstices filled with bitumen. The former type is of value for use as a surface binder in the construction of roads when the maltha shows good binding value and amounts to not less than 6 per cent of the weight of rock asphalt.

Semiasphaltic Petroleums.—Semiasphaltic petroleums or semiasphaltic oils are petroleums containing a semiasphaltic base, i. e., petroleums whose residues produced by evaporation or distillation, while composed mainly of asphaltic hydrocarbons, contain also a certain percentage of paraffin wax. They thus show a mixed base. If their percentage of heavy paraffin hydrocarbons is not excessive, they may be made to produce good dust preventives and road binders.

Short.—A term applied to bituminous materials which are nonductile.

Tar Pitches.—Semisolid or solid residual tars. Owing to the general brittleness of tar pitches, only the softer varieties are of value in their natural condition as road binders. The harder pitches may, however, be used for this purpose if fluxed to suitable consistency with heavy or dead oil distillates of tar.

Tars.—Tars are artificial or pyrogenetic bitumens produced as distillates by the destructive distillation of bitumens, pyrobitumens, and other organic material.

Water-Gas Tars.—Mixtures of hydrocarbon distillates, mostly unsaturated ring compounds, produced by cracking oil vapors at high temperatures in the manufacture of carbureted water gas. Crude water-gas tar is a thin, oily liquid having a specific gravity lying usually between 1 and 1.10. As a rule it contains a considerable quantity of water, which is, however, largely removed by mechanical devices before the tar is placed upon the market. This water is not ammoniacal, as in the case of crude coal tars. The composition of water-gas tar varies with the character of the oil which is carbureted and with varying conditions attending the carbureting process. It always shows a low percentage of free carbon, usually less than 2 per cent, and contains little or no naphthalene unless previously used for scrubbing coal gas. Crude water-gas tar has practically no binding value and is serviceable only as a dust palliative in the surface treatment of roads. When reduced to proper consistency by distillation, however, it shows certain desirable properties for use as a road binder both for surface treatment and macadam construction. Water-gas tar may also be used in the preparation of road binders from high-carbon coal tars. When this is done, the two crude tars are mixed in such proportion that when distilled to the desired consistency the mixture will contain less than the maximum limit of free carbon allowable.

Issued June 22, 1911.

U. S. DEPARTMENT OF AGRICULTURE,

OFFICE OF PUBLIC ROADS—Circular No. 94.

LOGAN WALLER PAGE, Director.

PROGRESS REPORTS OF EXPERIMENTS IN DUST PREVENTION AND ROAD PRESERVATION, 1910.

PREPARED BY THE OFFICE OF PUBLIC ROADS.

WASHINGTON:
GOVERNMENT PRINTING OFFICE.
1911.

LETTER OF TRANSMITTAL.

U. S. Department of Agriculture,
Office of Public Roads,
Washington, D. C., March 25, 1911.

Sir: I have the honor to transmit herewith a manuscript of a circular prepared by this office, entitled "Progress Reports of Experiments in Dust Prevention and Road Preservation, 1910." This is one of the series of progress reports which have been issued annually for the past five years and embody the results of experiments conducted by this office in all sections of the country. These circulars are being used more and more, and great interest has been shown in regard to their contents. I therefore request that this document be issued as Circular 94.

Respectfully,

Logan Waller Page,
Director.

Hon. James Wilson,
Secretary of Agriculture.

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PROGRESS REPORTS OF EXPERIMENTS IN DUST PREVENTION AND ROAD PRESERVATION, 1910.

INTRODUCTION.

During the year 1910 the Office of Public Roads conducted a number of experiments in dust prevention and road preservation, mainly along the lines followed in previous years. Descriptions of the earlier experiments from and including those for the year 1905 have already been published in Circulars 47, 89, 90 and 92. Reports of inspections of these experiments will be preceded by descriptions of those conducted during the past year.

EXPERIMENTS AT ITHACA, N. Y., 1910.

TAR, OIL, OIL-ASPHALT PREPARATIONS, AND ASPHALT BLOCK.

The experiments at Ithaca were a continuation of those conducted in 1909 by the Office of Public Roads in cooperation with Cornell University for the purpose of ascertaining the relative value of different road binders applied in a number of ways under given conditions. A full description of the 1909 experiments is to be found in Circular 92. A number of the road binders intended for use in 1909 could not be tried out during that year owing to bad weather in the fall, which made it necessary to stop work. These materials and a number of others were used during the past year.

Considerable time was lost during the summer in the hope of making arrangements to continue the experiments on State road No. 681, which is an extension of the road on which the experiments of 1909 were conducted. Such arrangements could not be satisfactorily made and it was therefore decided to make use of roads in the college grounds adjoining the road formerly treated. While this was unsatisfactory for a number of reasons, it was the best arrangement that could be made under the circumstances. The roads selected for these experiments were East Avenue and South Avenue. East Avenue intersects Forest Home Drive at the brick section, experiment No. 14, described in Circular 92, and runs south to South Avenue. Experiments were begun on East Avenue at Reservoir Avenue, a short distance south of the brick section, at station 0, and were continued to South Avenue. From the intersection of East Avenue with South Avenue the work ran west on South Avenue. Both of these roads are subjected to automobile and light draying traffic during the summer months and a considerable amount of heavy draying during the winter months. Loads of coal running from 4,000 to 6,000 pounds are of common occurrence during the latter period, especially on South Avenue.

Work was begun on September 12 and continued to November 16, when bad weather prevented its completion. It is hoped, however,

that all of the remaining materials will be laid early in 1911. In all 2,158 linear feet were completed during the past year. The work was carried on in the same general manner as that of 1909. According to previous arrangements, the university furnished all stone, machinery, and necessary labor; various manufacturers donated the bitumens and asphalt block; and the Office of Public Roads paid freight charges on donated materials and furnished supervision of the work. When so desired, the manufacturers had a representative present during the application of their material. In the experiments with the bitumens, two methods of construction, the penetration method and the mixing method, were employed. Materials applied during 1909 according to only one method were used according to the other method in the following experiments.

From station 0 at Reservoir Avenue to station 21 + 58 the road passes over an old macadam road, which was formerly rough and uneven. The old road was, therefore, spiked up with a 10-ton steam roller equipped with spikes. It was then harrowed with a spring-tooth harrow, which brought the coarse stone to the surface and allowed the dust and other fine material to sift down below. In places where the road was very uneven the old material was either taken out altogether or more of the old stone hauled in so as to make the surface even. From station 0 to station 5, five catch basins had been placed on the west side of the road for the purpose of draining the old road surface and preventing seepage from the hill on the east side. A slight fill was made from stations 9 to 12 with stone taken from the old road surface and bricks. The grade at this point was reduced to 3.5 per cent. From stations 15 + 50 to 17 + 35 a slight cut was made and the material excavated was used in a fill from station 17 + 35 to station 18 + 25. This reduced the maximum grade on the road to 4.5 per cent. When the drainage had been cared for, the road, which had been spiked up and harrowed, was rolled until firm with the 10-ton roller. A course of broken limestone ranging in size from 1 inch to 2½ inches was then spread over the road for a width of 20 feet. This course was approximately 2½ inches thick, but it varied in places sufficiently to bring the surface to the desired grade. After being rolled, it formed the foundation for the wearing surface of all of the sections hereafter described. The bituminous wearing surfaces were placed upon this foundation for a width of 16 feet and broken stone shoulders were constructed on the sides for a width of 2 feet, except in the asphalt block section.

The working equipment was the same as that used during the previous year. A 10-barrel tank fitted with a fire box and mounted on wheels was used for heating the bituminous binders, which were fed into the tank through a manhole in the top and, when heated, were drawn off through a spigot placed just over the fire box at the rear

of the tank. Owing to this arrangement, the entire contents of the tank had to be brought to the desired temperature before drawing off. Two 2-barrel iron soap kettles were also used for heating the bitumen used in the penetration method and also as a paint coat.

The mixing plant was located at the railroad siding at East Ithaca about one-half mile from the road. The equipment here consisted of four flat stone heaters made of $\frac{1}{8}$-inch sheet steel, each having a heating surface of from 75 to 80 square feet. These were used for heating the large-sized stone. A semicylindrical section of an old boiler was used for heating the screenings. A portable concrete batch mixer of the old McKelvey type was used for making the mixtures. It was driven by a gasoline engine connected by a chain drive. This mixer caused a considerable loss of time and labor owing to numerous breakdowns. Wheelbarrows loaded each time as nearly alike as possible were used in measuring and transporting the stone from the heaters to the mixer. They were also used for carrying the stone from the storage piles to the heaters. The prepared stone was hauled to the road in wagons.

The labor employed was unskilled and consisted of the regular campus force together with a few extra men. Common labor was figured at $1.75 per 9-hour day, foreman at $3, and double teams at $4. These figures were somewhat higher than for the preceding year. The engineer for the mixer was paid $4.50 per day. The roller was rented for the season for $200, which averaged about $3 per day. Wood at $3.50 per cord and coal at $1.65 per ton were used for fuel. Some scrap wood was also used. The stone used was a hard limestone, costing 70 cents per ton f. o. b. at the shipping point 80 miles away. Freight on this stone amounted to 50 cents per ton.

As in the preceding year's work, the cost of construction was excessive, owing to the shortness of the sections and the crude machinery and heating apparatus.

In order to avoid confusion the following experiments and sections have been numbered in sequence from those described in Circular 92. Thus, the last experiment conducted in 1909 was No. 14 and the last section No. 15. The first experiment described below is, therefore, No. 15 and the first section beginning at station 0 on East Avenue is No. 16.

Experiment No. 15, Section No. 16—Oil-Asphalt—Penetration Method.

The section treated in this experiment was 300 feet long and began at station 0. The wearing course of stone which ranged in size from $1\frac{1}{2}$ inches to one-half inch in diameter was laid 4 inches deep when loose and then rolled until firm. The bituminous material used in this experiment was an oil-asphalt similar to that used during the previous year in experiment No. 4, section No. 12, Mixing Method. Upon analysis it showed the following properties:

TABLE 1.—*Analysis of oil-asphalt*[1] *used in experiment No. 15.*

Specific gravity 25°/25° C	0.958
Melting point °C. (cube method)	69°
Penetration (No. 2 N, 5 seconds, 100 grams, 25° C.)	225°
Per cent of loss at 163° C., 5 hours (20 grams)	1.71
Penetration of residue[2] (as above)	184°
Per cent of total bitumen insoluble in 86° B. paraffin naphtha	22.26
Per cent of fixed carbon	8.87
Per cent of bitumen soluble in CS_2, air temperature (total bitumen)	99.78
Organic matter insoluble	.11
Inorganic matter	.11
	100.00

This material was heated to between 250° and 300° F., and then drawn off into coal scuttles fitted with strips of metal, which were riveted across their spouts, so as to give an opening 4½ inches across and one-half inch wide. The binder was then poured upon the prepared road surface at the rate of approximately 1 gallon per square yard. The surface was given a light coat of screenings (one-half inch in size and free from dust) and then rolled. More screenings were applied from time to time until all voids were filled. The surplus screenings and the dust caused by the grinding action of the roller wheels were then swept from the surface with rattan hand brooms and a paint coat of the hot bitumen was applied at the rate of one-half gallon to the square yard. Screenings were again applied in sufficient quantity to take up all surplus binder and the road was rolled until smooth and firm.

When last inspected on December 14, it was found that two spots, one about 5 feet square and the other 2 feet square, had begun to ravel. Owing to bad weather, these places were not repaired; they will, however, require attention at the beginning of spring. With this exception, the section was in excellent condition.

EXPERIMENT NO. 16, A AND B, SECTIONS NOS. 26 AND 27—REFINED ASPHALTIC PREPARATION—PENETRATION METHOD.

The two sections treated in this experiment had a total length of 252 feet, beginning at station 19 + 06 on East Avenue and running to station 21 + 58 on South Avenue. The foundation was prepared in the same manner as for all of the other experiments. Upon this foundation the wearing course of broken stone ranging from 2 inches to one-half inch in diameter was laid 4 inches deep when loose. Clean, sharp bank sand was then applied to a depth of one-half inch over the surface. This sand was somewhat damp and a steel-tooth harrow was used to stir it until dry, and work it into the course of stone so as to fill the voids fairly well when rolled. The hot binder was then poured over the surface at the rate of approximately three-

[1] Semisolid, sticky.

[2] Considerably harder, surface dull.

fourths of a gallon per square yard, and immediately covered with a layer of three-fourths-inch broken stone spread just thick enough to cover the surface.

The properties of this binder, which was shipped in barrels, are shown in Table 2.

TABLE 2.—*Refined asphaltic preparation*[1] *used in experiment No. 16, A and B.*

Specific gravity 25°/25° C	1.004
Float test at 32° C. (time)	2′ 51″
Flash point °C	90°
Burning point °C	130°
Per cent of loss at 163° C., 5 hours (20 grams)	8.37
Float test on residue at 50° C. (time)	17′ 29″
Penetration of residue[2] (No. 2 N, 5 seconds, 100 grams, 25° C.)	64°
Per cent of total bitumen insoluble in 86° B. paraffin naphtha	17.88
Per cent of fixed carbon	12.21
Per cent of bitumen soluble in CS_2, air temperature (total bitumen)	97.94
Organic matter insoluble	1.41
Inorganic matter	.65
	100.00

(*a*) The road was next rolled until firm, after which another application of the binder was made in the same manner as before at the rate of approximately three-fourths of a gallon to the square yard. Stone screenings were then applied in sufficient quantity to fill the surface voids and take up all excess of binder, and the road was finished by rolling until smooth and solid. A total length of 106 feet, constituting section 26, was thus treated.

(*b*) Cold, rainy weather made it necessary to discontinue the work at this point, although 146 feet had already been given one application of the binder. This section was, therefore, given a heavy coat of screenings to protect it against traffic until spring, when it should be completed.

EXPERIMENT No. 17, SECTION No. 18.—OIL-ASPHALT—MIXING METHOD.

The section treated in this experiment was 300 feet in length and began at station 3 + 50. Broken stone heated in the manner previously described was used in the proportion of 6 parts by weight of from 1½-inch to ½-inch stone to 2 parts of ½-inch screenings free from dust. These two sizes of stone were measured in wheelbarrows and carried to the mixer. The coarse stone was first dumped into the mixer and then the bituminous binder, heated to about 250° F., was added. After the mixer had made a few turns, the screenings were dumped in and the mixing continued until the stone had become thoroughly coated with the binder. The mixture was then dumped into wagons and hauled to the road, where it was spread on the foun-

[1] Viscous, sticky. [2] Semisolid, sticky; surface glassy.

dation from a dumping board to a depth of from 3½ to 4 inches. After a light coat of stone chips, ranging from one-half to one-fourth inch in diameter, had been applied to keep the bitumen from sticking to the roller wheels, this course was well rolled. While rolling, more chips were added as required and, when thoroughly rolled, the surface was painted with about one-half gallon of the bitumen per square yard. Enough stone chips were then added to take up all surplus bitumen, and the road was finished with another rolling. This section presented a good appearance, and was firm and well bonded when finished.

The properties of the bitumen used are shown in Table 3.

TABLE 3.—*Oil-asphalt*[1] *used in experiment No. 17.*

Specific gravity 25°/25° C	0.991
Melting point °C. (cube method)	37°
Penetration (No. 2 N, 5 seconds, 100 grams, 25° C.)	187°
Per cent of loss at 163° C., 5 hours (20 grams)	0.92
Penetration of residue[2] (as above)	116°
Per cent of total bitumen insoluble in 86° B. paraffin naphtha	18.93
Per cent of fixed carbon	9.56
Per cent of bitumen soluble in CS_2, air temperature (total bitumen)	99.82
Organic matter insoluble	.11
Inorganic matter	.07
	100.00

EXPERIMENT NO. 18, A AND B, SECTIONS NOS. 20 AND 21.—SEMISOLID, REFINED, SEMIASPHALTIC OIL—MIXING METHOD.

The sections treated in this experiment had a total length of 300 feet and began at station 7+26. The wearing course for both was mixed and laid in the same manner as described in experiment No. 17. The bitumen used showed the following properties upon analysis:

TABLE 4.—*Semisolid, refined, semiasphaltic oil*[3] *used in experiment No. 18, A and B.*

Specific gravity 25°/25° C	0.985
Melting point °C. (cube method)	43°
Penetration (No. 2 N, 5 seconds, 100 grams, 25° C.)	242°
Per cent of loss at 163° C., 5 hours (20 grams)	0.43
Penetration of residue[4] (as above)	137°
Per cent of total bitumen insoluble in 86° B. paraffin naphtha	20.29
Per cent of fixed carbon	11.98
Per cent of bitumen soluble in CS_2, air temperature (total bitumen)	99.70
Organic matter insoluble	.19
Inorganic matter	.11
	100.00

(*a*) For a distance of 206 feet, constituting section No. 20, the wearing surface was rolled, after screenings had been added, and then painted with hot bitumen and finished off in the same manner as described in experiment No. 17.

[1] Semisolid, sticky

[2] Semisolid, sticky; surface lustrous.

[3] Semisolid, sticky.

[4] Considerably harder; surface dull and granular.

(*b*) On the remaining 94 feet, constituting section No. 21, no paint coat was applied. The surface here was finished off by rolling in stone chips until the road was firm. The surface of this section was slightly rougher than that of No. 20, but quite satisfactory.

Experiment No. 19, A and B, Sections Nos. 22 and 23.—Refined Water-Gas Tar—Mixing Method.

The two sections in this experiment had a total length of 300 feet, beginning at station 10+26. The wearing course was mixed and laid in exactly the same manner as described under experiment No. 17, with the exception that a heavy, refined water-gas tar was used as a binder. The properties of this material are shown in Table 5.

Table 5.—*Analysis of heavy refined water-gas tar*[1] *used in experiment No. 19.*

Specific gravity 25°/25° C	1.171
Float test at 32° C. (time)	20′ 17″
Per cent of free carbon (insoluble in CS_2, air temperature)	.56

Distillation:	Per cent by volume.	Per cent by weight.
Water	0.0	0.0
First light oils to 110° C	.1	.1
Second light oils 110°–170° C	.2	.2
Dead oils 170°–270° C	[2] 23.8	20.1
Pitch residue	[3] 75.9	79.0
	100.0	99.4

(*a*) For a distance of 130 feet, constituting section No. 22, the wearing surface was rolled, after screenings had been added, and then painted with hot bitumen and finished off in the same manner as described in experiment No. 17.

(*b*) On the remaining 170 feet, constituting section No. 23, the surface was finished with a coat of tarred screenings instead of a paint coat. The screenings were mixed in the mixer and hauled to the road, where they were spread while hot to a depth of one-half inch. The road was then rolled and a thin layer of screenings, not treated with tar, was applied to take up the surplus binder, after which the road received another rolling. When finished, this section had a smooth, hard surface, but at the end of 10 days, after it had been opened to traffic, both (*a*) and (*b*) raveled badly in places. As many as possible of these raveled places were repaired before bad weather set in, but indications point to a continued disintegration. For the last 51 feet of section 23, a cinder-cement-concrete combined curb and gutter was built on each side. This is described under section No. 24, for which it was built. No cost for this work is, therefore, included in the cost data for this experiment.

[1] Very viscous, sticky.
[2] Distillate clear.
[3] Pitch residue, hard, brittle, and lustrous.

EXPERIMENT No. 20, SECTION No. 25.—OIL-ASPHALT—MIXING METHOD.

The section treated in this experiment is 296 feet in length and begins at station 16 + 10. The wearing course was mixed, laid, and finished off in the same manner as described under experiment No. 17. In the last 146 feet, however, stone from 1 inch to ¾ inch in size was used in the mixture in place of that ranging from 1½ inches to ½ inch. When this section was opened to traffic, it raveled badly and rutted under heavily loaded wagons. The manufacturers of this product, realizing that it was too brittle, signified their desire to treat this section with a paint coat of a lighter material. It was finally decided, however, to defer such treatment until spring, if it was then needed. A cinder-cement-concrete combined curb and gutter was placed along each side of this section for the first 25 feet. As this was done in connection with section No. 24, no cost for the work is shown in the cost data of this experiment.

The properties of the binder used in this experiment are shown in the following table:

TABLE 6.—*Analysis of oil-asphalt*[1] *used in experiment No. 20.*

Specific gravity 25°/25° C.	1.061
Melting point ° C. (cube method)	108°
Penetration (No. 2 N, 5 seconds, 100 grams, 25° C.)	11°
Per cent of loss at 163° C., 5 hours (20 grams)	0.00
Penetration of residue[2] (as above)	11°
Per cent of total bitumen insoluble in 86° B. paraffin naphtha	32.74
Per cent of fixed carbon	22.03
Per cent of bitumen soluble in CS_2, air temperature (total bitumen)	99.84
Organic matter insoluble	.16
Inorganic matter	.00
	100.00

EXPERIMENT No. 21, SECTION No. 17.—OIL-ASPHALT—PREPARED-FILLER METHOD.

Section No. 17 is 50 feet in length. The prepared-filler method of construction may be described as one in which the wearing course of stone is bound with a filler composed of a mixture of stone screenings and bitumen. The foundation for this work was prepared in exactly the same manner as described for all of the preceding experiments. Upon this foundation a wearing course of crushed rock ranging from 1½ inches to ½ inch in diameter was laid to a depth of approximately 4 inches. This course was then covered to a depth of from 1½ inches to 2 inches with the prepared filler, consisting of a mixture of stone chips, sand, and the oil-asphalt described in experiment No. 15. Both the aggregate and bitumen were first heated and then mixed in the mechanical mixer. The proportions of the constituents of this mixture were as follows: 11 cubic feet of

[1] Hard, brittle. [2] No apparent change.

stone screenings from ½ inch to ¼ inch in size, 4½ cubic feet of sand, and 5 gallons of bitumen.

After the filler had been spread, it was harrowed with a light spike-tooth harrow, which worked it down into the wearing course. About four trips of the harrow were required to do this so that the coarse stone appeared on the surface. At this point the road was rolled until it did not creep under the roller and a paint coat of the hot bitumen was then applied at the rate of ½ gallon to the square yard. The road was finished with a light coat of stone chips which were rolled down in sufficient quantity to fill the surface voids and take up all excess of bitumen.

Experiment No. 22, Section No. 19.—Oil-Asphalt—Prepared-Filler Method.

This section is 76 feet in length. The method of construction was identical with that described under experiment No. 21, with the exception that the surface was finished off with a coat of the prepared filler about ½ inch thick instead of the paint coat. Results so far obtained would seem to indicate that such a surface is preferable to the paint coat. The bitumen used in this experiment is the same as that described in experiment No. 17.

Experiment No. 23, Section No. 24.—Asphalt Block.

Section No. 24 extends from station 13 + 26 to station 16 + 10, a distance of 284 feet in all. The foundation for this experiment was prepared in the same manner as for the other experiments except that ½-inch screenings were used in place of the No. 2 stone.

A cinder-cement-concrete combined curb and gutter was built on each side of the section. The curb was 6 inches high and the gutter was 15 inches wide, and both were 6 inches thick. The body of the curb and gutter was composed of a mixture of Portland cement, sand, and cinders in the proportion of 1: 2: 3, respectively. Both were faced about 1 inch thick with a mixture of one part of Portland cement and three parts of sand.

A mixture (1:4) of Portland cement and sand, moistened so that it would stick together when compressed, was spread over the foundation for a depth of from 1 to 2 inches and was then struck off with a template having a crown of ½ inch to the foot. When the surface was thus made smooth, the asphalt blocks were laid on the sand-cement cushion, flush with the top of the gutter, under the supervision of a skilled block layer. Twenty-one blocks were required for each square yard. After the entire section had been laid, a thin layer of clean sand was spread over the surface so as to fill the joints between the blocks. This section was not opened to traffic for about 10 days after completion, in order to give the cement-sand cushion time to set thoroughly. Most of the sand and cement was mixed by hand on a mixing board, although the concrete mixer was also used to some extent for this purpose.

The properties of the asphalt block are shown in the following table:

TABLE 7.—*Analysis of asphalt blocks used in experiment No. 23.*

Per cent soluble in CS_2, air temperature (total bitumen)	6.25
Per cent of mineral matter, etc	93.75
Per cent retained on a 10-mesh sieve	25.2
Per cent passing 10, retained on a 20-mesh	18.0
Per cent passing 20, retained on a 30-mesh	6.7
Per cent passing 30, retained on a 50-mesh	8.2
Per cent passing 50, retained on a 80-mesh	7.1
Per cent passing 80, retained on a 100-mesh	4.3
Per cent passing 100, retained on a 200-mesh	12.0
Per cent passing 200-mesh	18.5
	100.0
Extracted bitumen:[1]	
Specific gravity 25°/25° C	1.055
Penetration (No. 2 N, 5 seconds, 100 grams, 25° C.)	37°
Per cent of loss at 163° C., 5 hours (20 grams)	0.10
Penetration of residue [2] (as above)	30°
Per cent of bitumen insoluble in 86° B. paraffin naphtha	29.77
Per cent of fixed carbon	7.04

SUMMARY OF EXPERIMENTS AT ITHACA, N. Y.

When last inspected, on December 14, 1910, all of the sections were in fairly satisfactory condition with the exception of Nos. 16, 22, and 25. The final results will be published later. The cost data for the various experiments are given in Tables 8 and 9.

TABLE 8.—*Items of cost.*

EXPERIMENT NO. 23, SECTION NO. 24—ASPHALT BLOCK.

Length of section	feet	284
Area of section	square yards	533
Length of curbing	feet	568
Sand and cement cushion per square yard	cubic yards	.042
Number of blocks per square yard		21
Cost of curb and gutter per running foot	cents	23.52
Cost of preparing old road foundation per square yard	cents	8.67
Cost of hauling and laying blocks	do	17.97
Cost of block per square yard	do	98.70
Cost of freight on blocks per square yard	do	31.08
Cost of cement and sand cushion per square yard	do	9.38
Miscellaneous expenses per square yard	do	1.62
Cost of curb and gutter per square yard of road	do	26.46
Total cost per square yard	do	193.88
Total cost of entire section		$1,033.38

[1] Hard, smooth, glossy surface. [2] But slightly changed.

TABLE 9.—*Materials and cost data of experiments at Ithaca, N. Y.*

PENETRATION METHOD.

Experiment No.	Section No.	Description.				Quantity of materials.								Cost data (cents per square yard).												Total cost—			
		Binding materials.	Course.	Length of section (feet).	Area of section (square yards).	No. 2 stone (cubic yards per square yard).	Screenings (cubic yards per square yard).	Binder, first application (gallons per square yard).	Binder, second application (gallons per square yard).	Screenings used on stone shoulders (cubic yards per square yard).	Sand used on shoulders (cubic yards per square yard).	Sand filler (cubic yards per square yard).	$\frac{3}{4}$-inch stone used (cubic yards per square yard).	No. 2 stone at siding.	$\frac{3}{4}$-inch stone at siding.	Screenings at siding.	Hauling and laying stone.	Binder.	Hauling binder.	Heating and applying binder.	Rolling.	Miscellaneous.	Freight on binder.	Grading.	Hauling and spreading sand.	Cents (per square yard).	Entire section.	Foundation and wearing surface (cents per square yard).	Entire section—foundation and wearing surface.
15	16	Oil-asphalt......	Foundation.....	300	667	0.042	.....	.....	.....	0.025	.....	.....	.....	6.34	....	3.17	5.29	.....	.....	.....	3.09	1.30	....	4.28	....	23.47	$156.55	79.10	$421.61
15	16	.....do..........	Wearing surface.	300	533	.113	0.021	1.00	0.50	.....	.....	.....	.....	17.06	....	3.17	5.78	11.25	1.90	1.85	5.01	1.62	2.09	....	....	49.73	265.06		
16a 16b	26 27	Refined asphaltic preparation.	Foundation.....	252	586	.....	.....	.....	.....	.025	0.016	.....	.....	.....	.....	.....	.....	.....	.....	.....	3.09	1.30	....	4.28	0.03	8.70	50.98	......	......
16a	26	.....do..........	Wearing surface.	106	308	.100	.034	.80	.80	.....	.....	0.021	0.024	15.10	3.62	5.13	8.98	18.40	1.01	6.76	5.01	1.62	3.70	....	.03	69.36	213.63	78.34	241.28
16b	27	.....do..........	.....do.........	146	260	.100	.034	.80	.00	.....	.....	.021	.024	15.10	3.62	5.13	8.98	9.20	.51	3.38	5.01	1.62	1.85	....	.03	54.43	141.52	63.40	164.86

TABLE 9—*Materials and cost data of experiments at Ithaca, N. Y.*—Continued.

PREPARED-FILLER METHOD.

Description.						Quantity of materials.								Cost data (cents per square yard).											Total cost—			
Experiment No.	Section No.	Binding materials.	Course.	Length of section (feet).	Area of section (square yards).	No. 2 stone (cubic yards per square yard).	Prepared filler, first application (cubic yards per square yard).	Prepared filler, second application (cubic yards per square yard).	Screenings (cubic yards per square yard).	Binder in mixture, first application (gallons per square yard).	Binder in mixture, second application (gallons per square yard).	Binder in paint coat (gallons per square yard).	Screenings used on shoulders (cubic yards per square yard).	No. 2 stone at siding.	Mixed stone at siding.	Screenings at siding.	Binder.	Hauling and laying No. 2 stone.	Preparing and laying mixture.	Heating and applying paint coat.	Freight on binder.	Rolling.	Miscellaneous.	Grading.	Cents (per square yard).	Entire section.	Foundation and wearing surface. Basis of wearing surface (cents per square yard).	Entire section—foundation and wearing surface.
21	17	Oil-asphalt........	Foundation..........	50	111	0.042	.....	.....	.....	....	....	....	0.025	6.34	.....	3.17	.....	5.29	....	....	....	3.09	1.30	4.28	23.47	$26.05	83.69	$74.48
21	17	.....do.............	Wearing surface.....	50	89	.111	0.042	.....	0.021	0.90	....	0.50	.....	16.76	6.34	3.17	10.50	5.78	3.40	1.50	1.96	5.01	....	....	54.42	48.43		
22	19	.....do.............	Foundation..........	76	169	.049	.....	.....	.....	....	....	....	.025	7.40	.....	3.17	.....	5.85	....	....	....	3.09	1.30	4.28	25.09	42.40	92.34	124.66
22	19	.....do.............	Wearing surface.....	76	135	.111	.055	0.014	.021	.98	0.25	....	.....	16.76	10.42	3.17	14.15	3.37	5.59	....	2.46	5.01	....	....	60.93	82.26		

TABLE 9.—*Materials and cost data of experiments at Ithaca, N. Y.*—Continued.

MIXING METHOD.

Experiment No.	Section No.	Description.				Quantity of materials.						Cost data (cents per square yard).												Total cost—			
		Binding materials.	Course.	Length of section (feet).	Area of section (square yards).	No. 2 stone (cubic yards per square yard).	Mixed stone (cubic yards per square yard).	Screenings (cubic yards per square yard).	Binder in mixture (gallons per square yard).	Binder used in paint coat (gallons per square yard).	Screenings used on stone shoulders (cubic yards per square yard).	No. 2 stone at siding.	Stone used in mixture at siding.	Screenings at siding.	Hauling and laying stone.	Binder.	Hauling mixture.	Preparing and laying mixture.	Heating and applying paint coat.	Rolling.	Miscellaneous.	Freight on binder.	Grading.	Cents (per square yard).	Entire section.	Foundation and wearing surface. Basis of wearing surface (cents per square yard).	Entire section—foundation and wearing surface.
17	18	Oil-asphalt	Foundation	300	667	0.049	.....	.....	.....	.....	0.025	7.40	.....	3.17	5.85	.....	.....	.....	.....	3.09	1.30	....	4.28	25.09	$167.35	113.58	$605.37
17	18	....do	Wearing surface	300	533	.....	0.119	0.021	0.88	0.55	.....	....	17.97	3.17	....	16.45	3.37	29.60	2.13	5.01	1.62	2.86	....	82.18	438.02		
18a, 18b	20, 21	Refined semiasphaltic oil	Foundation	300	667	.054	.....	.....	.....	.....	.025	8.15	.....	3.17	6.24	.....	.....	.....	.....	3.09	1.30	....	4.28	26.23	174.95	....	....
18a	20	....do	Wearing surface	206	366	.....	.113	.021	.83	.55	.....	....	17.06	3.17	....	9.66	4.83	26.98	2.17	5.01	1.62	1.99	....	72.49	265.32	105.32	385.45
18b	21	....do	....do	94	167	.....	.113	.021	.83	.00	.....	....	17.06	3.17	....	5.81	4.83	26.48	.00	5.01	1.62	1.20	....	65.18	108.85	98.00	163.66
19a, 19b	22, 23	Refined water-gas tar	Foundation	300	667	.046	.....	.....	.....	.....	.025	6.95	.....	3.17	5.61	.....	.....	.....	.....	3.09	1.30	....	4.28	24.40	162.75	....	....
19a	22	....do	Wearing surface	130	231	.....	.119	.021	.88	.55	.....	....	17.97	3.17	....	10.01	3.83	17.29	1.17	5.01	1.62	2.77	....	62.84	145.16	93.37	215.70
19b	23	....do	....do	170	302	.....	.119	[1].017	.88	[1]1.13	.....	....	17.97	2.57	....	7.07	4.38	19.76	.00	5.01	1.62	1.96	....	60.34	182.23	90.87	274.44
20	25	Oil-asphalt	Foundation	296	658	.046	.....	.....	.....	.....	.025	6.95	.....	3.17	5.61	.....	.....	.....	.....	3.09	1.30	....	4.28	24.40	160.55	102.78	540.64
20	25	....do	Wearing surface	296	526	.....	.132	.021	.98	.55	.....	....	19.93	3.17	....	15.30	3.43	18.42	1.47	5.01	1.62	3.91	....	72.26	380.09		

[1] Mixed for surface binder.

EXPERIMENTS AT KNOXVILLE, TENN., 1910.

TAR AND OIL PREPARATIONS.

The road selected for these experiments is known as Rutledge Pike and is one of the main county roads leading into Knoxville. It is subjected to heavy automobile and country traffic the year round. The section selected for these experiments was an old macadam road beginning at the old schoolhouse and running northeast to Lake Street, a distance of 980 feet. All of the intersecting streets are clay.

The work was begun on July 25 and finished September 7. For all of the experiments a foundation was prepared as follows: The old road, which was very uneven, was first spiked up with a steam road roller equipped with spikes. It was then brought to a true grade with a road machine and slips, and after this a spike-tooth harrow was used to bring the coarse stone to the surface and work the fine material down. Crushed limestone, ranging from 2 inches to $\frac{3}{4}$ inch in diameter, was then spread over the road to a depth of 2 inches and rolled with a 10-ton roller until firm. This stone was a soft limestone costing 90 cents per cubic yard f. o. b. street cars at the crusher, about 5 miles from the road. Freight amounted to 30 cents per cubic yard. The stone used in the bituminous wearing surfaces was fine grained and very hard, and was known locally as iron limestone. This material cost 67½ cents per cubic yard at the crusher, from which it was hauled to the road in wagons holding 1½ cubic yards each. One team could haul 6 cubic yards per day.

The road was constructed 20 feet in width, with a 3-foot earth shoulder on each side. Station 0 was opposite the old schoolhouse. From station 5 + 50 to station 10 the road was about level with the surrounding country, and it was therefore found necessary to cut side ditches low enough to secure good drainage. A 15-inch corrugated iron cross drain, which emptied into an outlet ditch, was placed at station 6 + 05 and an 8-inch cast-iron drain 36 feet long was placed across Lake Street at the intersection.

A crown of one-half inch to the foot was adopted for both the foundation and the bituminous wearing surfaces. The bituminous binders were heated in two 120-gallon unmounted kettles and applied according to the penetration method. These kettles were not equipped with fire boxes, so that heating and applying the bitumens proved a slow and costly operation. Two sections of roadway were constructed with refined tars and one with an oil asphalt.

The labor employed was unskilled, and consisted mainly of negroes. Common labor for the foundation work was figured at $1.35 per 10-hour day, and for the bituminous work at $1.50 per 10-hour day. Double teams cost $3.50 per day, and the roller and operator $3 per day.

EXPERIMENT NO. 1, SECTION NO. 1.—REFINED COAL TAR—PENETRATION METHOD.

The section treated in this experiment begins at station 0 + 25 and is 217 feet in length. Upon the foundation, prepared in the manner previously described, a wearing course of the hard limestone crushed to sizes ranging from 2 inches to ¾ inch in diameter was laid loose to a depth of 4 inches. This stone was clean and free from dust. The road was then rolled with the 10-ton steam roller until firm, and after this the binder was applied, heated to between 250° and 300° C. Application was made at the rate of 1½ gallons per square yard by pouring the hot binder from coal scuttles, fitted with strips of metal across their spouts, so as to give an opening 4½ inches across and ¼ inch wide. The road surface was then given a light coat of ½-inch stone screenings, free from dust, and rolled. More screenings were applied from time to time until all surface voids were filled.

The surplus screenings and dust caused by the crushing action of the roller were then swept from the surface with rattan hand brooms and a paint coat of hot tar was applied at the rate of one-half gallon to the square yard. Screenings were again applied in sufficient quantity to take up all excess of binder and the surface was well rolled. The road did not "set up" satisfactorily, but waved under the roller, so that the use of a large quantity of screenings was required to obviate this difficulty. Even then the surface failed to bond as was desired. After 10 days the road was opened to traffic, which caused raveling in three or four places. Owing to the fact that the supply of tar had been exhausted, these places were patched with the material used in experiment No. 3. After this section had been opened for about three weeks, the road became smooth and solid.

The properties of the binder used in this experiment are given in the following table. It was used upon request, owing to the fact that a small supply was already on hand at Knoxville. The price of this material at the storehouse was 11 cents per gallon.

TABLE 10.—*Analysis of refined coal tar*[1] *used in experiment No. 1.*

Specific gravity 25°/25° C		1.249
Float test at 32° C. (time)		1′ 47″
Float test at 50° C. (time)		44″
Per cent of free carbon (insoluble in CS_2, air temperature)		26.31
Distillation:	Per cent by volume.	Per cent by weight.
Water	Trace.	Trace.
First light oils to 110° C	0.4	0.2
Second light oils 110°–170° C	[2] 2.2	1.6
Dead oils 170°–270° C	[3] 24.9	20.0
Pitch residue	[4] 72.5	77.7
	100.0	99.5

[1] Viscous, fluid, sticky.
[2] Turbid.
[3] Distillate showed about one-half its volume precipitated solids when cold.
[4] Hard, brittle, dull fracture.

Experiment No. 2, Section No. 2.—Refined Tar Preparation—Penetration Method.

Section No. 2 was constructed in the same manner as No. 1, with the exception that a different tar binder was employed. This section begins at station 2 + 42 and is 590 feet in length. The properties of the tar binder, which was a refined mixture of coal tar and water-gas tar, are shown in the following table. It was made to conform with specifications drawn up by the Office of Public Roads.

Table 11.—*Analysis of refined tar preparation*[1] *used in experiment No. 2.*

Specific gravity 25°/25° C		1.244
Float test at 50° C. (time)		4′ 29″
Per cent of free carbon (insoluble in CS_2, air temperature)		17.13
Distillation:	Per cent by volume.	Per cent by weight.
Water	0.0	0.0
First light oils to 110° C	.0	.0
Second light oils 110°–170° C	[2] .4	.3
Dead oils 170°–270° C	[3] 23.2	18.8
Pitch residue	[4] 76.4	80.4
	100.0	99.5

Experiment No. 3, Section No. 3.—Oil-Asphalt—Penetration Method.

Section No. 3 begins at station 8 + 32 and is 173 feet in length. It was constructed in exactly the same manner as section No. 1, with the exception that an oil-asphalt was used instead of tar for a binder. This material was shipped in 40-gallon thin sheet-iron containers. After the containers had been cut and stripped from the oil-asphalt, it was cut with hot ax blades into pieces small enough to be heated suitably. The properties of the binder are given in the following table:

Table 12.—*Analysis of oil-asphalt*[5] *used in experiment No. 3.*

Specific gravity 25°/25° C	0.998
Penetration (No. 2 N, 5 seconds, 100 grams, 25° C.)	86°
Per cent of gain at 163° C., 5 hours (20 grams)	0.02
Penetration of residue[6] (as above)	75°
Per cent of total bitumen insoluble in 86° B. paraffin naphtha	22.88
Per cent of fixed carbon	13.78
Per cent of bitumen soluble in CS_2, air temperature (total bitumen)	99.85
Organic matter insoluble	.10
Inorganic matter	.05
	100.00

The cost data of these experiments are given in Table 13.

[1] Very viscous, sticky.
[2] Clear.
[3] Distillate showed about two-fifths its volume precipitated solids when cold.
[4] Hard, fairly lustrous.
[5] Semisolid, sticky.
[6] Slightly harder, otherwise unchanged.

SUMMARY OF EXPERIMENTS AT KNOXVILLE, TENN.

When last inspected, on December 17, all of the sections treated in these experiments appeared satisfactory in so far as the work itself was concerned. The weather for some time previous had been cold and rainy, and a considerable amount of clay had been tracked on the road from adjoining streets. This clay mud covered the surface for a depth of approximately 1 inch.

The material used in experiment No. 2, page 20, was shipped in two lots, one of which contained a little water because the barrels had been exposed to the rain. When this water was removed, the tar was easily handled and produced a satisfactory section.

TABLE 13.—*Materials and cost data of experiment at Knoxville, Tenn.*

Experiment No.	Section No.	Description.			Quantity of material.				Cost data (cents per square yard).										Total cost—			
		Binding materials.	Length of section (feet).	Area of section (square yards).	No. 2 stone (cubic yards per square yard).	Screenings (cubic yards per square yard).	Binder, first application (gallons per square yard).	Binder, second application (gallons per square yard).	No. 2 stone at crusher.	Screenings at crusher.	Hauling and laying stone.	Binder.	Hauling binder.	Heating and applying binder.	Rolling.	Grading.	Miscellaneous.	Freight on binder.	Cents (per square yard).	Entire section.	Foundation and wearing surface (cents per square yard).	Entire section—foundation and wearing surface.
1-3	1-3	Foundation	980	2,198	0.054	......	......	......	[2]6.48	......	1.72	......	......	......	1.23	3.72	......	......	13.15	$289.04	......	......
1	1	Refined coal tar	217	482	.117	0.022	1.49	0.50	7.90	1.48	8.90	21.89	0.36	2.78	1.27	......	2.31	0.00	46.89	226.01	60.04	$289.39
2	2	Refined tar preparation	590	1,311	.117	.022	1.21	.50	7.90	1.48	8.90	10.26	.19	3.24	.80	......	2.31	5.75	40.83	535.28	53.98	707.68
3	3	Oil-asphalt	173	[1]405	.117	.022	1.69	.50	7.90	1.48	8.90	16.10	.00	2.96	.91	......	2.31	.00	40.56	164.27	53.71	217.53

[1] Includes intersection of Lake Street.

[2] No. 2 stone at siding.

EXPERIMENT AT AMES, IOWA, 1910.

OIL-ASPHALT-GRAVEL.

The experiment at Ames was conducted by the Office of Public Roads in cooperation with the Iowa State highway commission. Early in the year it had been the intention of the commission to try a number of experiments in bituminous-road construction, but for various reasons it was finally decided to postpone this work until the spring of 1911. However, as one manufacturer had already donated a certain quantity of oil-asphalt, it was thought best to try this material in 1910.

The road selected for this experiment was an old gravel road in the grounds of the Iowa State Agricultural College, beginning at the south gate. The section of this road that was resurfaced begins at the south gate and runs north for a distance of 300 feet. It has an average width of 27 feet, running from a cement curb and gutter on the western side to an old brick gutter with no curb on the eastern side. The old road was about 6 inches thick and had been regraveled during the spring. While well bonded during a good portion of the year, it became very dusty in dry weather. Traffic over it is rather light. This section was surfaced with gravel and oil-asphalt as described below.

Work was begun on September 19. Common labor for this experiment was figured at $50 per month; foreman, at $75; double teams and driver, at $4.50 per day; and roller, at $10 per day. The labor consisted of the campus force. A tar kettle holding about 10 barrels was loaned for this work. The gravel used was a local product costing 25 cents per cubic yard at the pit. It was very fine, and consisted principally of stone, pea-sized and smaller, but contained comparatively little clay or silt. The oil-asphalt was figured at 7¾ cents per gallon at Ames. Scrap wood for heating the bitumen cost 50 cents per load. The properties of the oil-asphalt are given in the following table:

TABLE 14.—*Analysis of oil-asphalt*[1] *used in experiment at Ames, Iowa.*

Specific gravity 25°/25° C	0.988
Melting point °C. (cube method)	83°
Penetration (No. 2 N, 5 seconds, 100 grams, 25° C.)	95°
Per cent of loss at 163° C., 5 hours (20 grams)	0.08
Penetration of residue[2] (as above)	75°
Per cent of total bitumen insoluble in 86° B. paraffin naphtha	23.79
Per cent of fixed carbon	15.64
Per cent of bitumen soluble in CS_2, air temperature (total bitumen)	95.45
Organic matter insoluble	4.27
Inorganic matter	.28
	100.00

[1] Semisolid, short, cheesy. [2] Not much changed.

In this work the old road was first prepared by working it with a disk harrow until the surface had been loosened to a depth of approximately 2 inches. Fresh gravel was then applied and spread with a road grader until the road was well shaped. The loose gravel was harrowed with a spring-tooth harrow until the coarsest material appeared on the surface, after which it was ready to receive the application of oil-asphalt.

The oil-asphalt had been shipped in thin sheet-iron drums. These were removed by rolling the drums on two pieces of iron rail over a small fire built in the gutter. The sheeting was first cut into strips, which were afterwards peeled off as the bitumen next to the metal melted. The oil-asphalt was then cut into pieces of suitable size by means of a wire, and heated in the kettle to about 300° C. It was applied to the prepared road surface by pouring from coal scuttles fitted with a strip of metal across their spouts so as to form a slot approximately one-half inch wide and $4\frac{1}{2}$ inches across. Application was made at the rate of approximately $1\frac{1}{2}$ gallons to the square yard. On a part of this section the gravel was first raked back for a distance of 3 feet, and the hot bitumen was applied and then covered with the gravel which had been raked back. This operation was repeated a number of times.

Shortly after application the oil-asphalt cooled in a tough, leathery sheet over the entire road without penetrating to any appreciable extent. At this point the road was thoroughly saturated with water, supplied from a near-by hydrant, by means of a hose. It was then worked for some time with a disk harrow on which the disks had been reversed. By this means the sheet of bitumen was first cut into strips and then cut and worked into the wet gravel to a considerable extent. The mixing process was hastened somewhat by running the harrow at an angle crisscross over the surface. After as good a mixture as possible had thus been secured, the road was allowed to dry out to a considerable extent, when it was rolled with a 10-ton steam roller until smooth. The finished surface had a crown of a little over one-half inch to the foot, and when last inspected, on October 12, had the appearance of a rather dirty asphalt pavement. The bitumen was not mixed with the gravel as completely as might have been desired, owing largely to the hardness of the oil-asphalt. A somewhat lighter product could undoubtedly have been handled better and would have given more satisfactory results. The materials and cost data of this experiment are given in the following table:

TABLE 15.—*Materials and cost data for experiment at Ames, Iowa.*

Length of section	feet	300
Area of section	square yards	900
New gravel per square yard	cubic yard	.053
Oil-asphalt per square yard	gallons	1.41
Cost of shaping old road per square yard	cents	0.830
Cost of hauling gravel per square yard	do	1.401
Cost of gravel per square yard	do	.014
Total cost of preparing surface per square yard	do	2.245
Cost of hauling oil-asphalt per square yard	do	.266
Cost of hauling fuel per square yard	do	.180
Cost of heating and applying oil-asphalt per square yard	do	2.217
Cost of oil-asphalt delivered at Ames per square yard	do	10.951
Cost of fuel per square yard	do	.167
Cost of mixing oil-asphalt on road per square yard	do	.748
Cost of rolling per square yard	do	.333
Miscellaneous expenses per square yard	do	.675
Total cost of oil work per square yard	do	15.537
Total cost of all work per square yard	do	17.782
Total cost of entire section		$160.04

EXPERIMENT AT BOISE, IDAHO, 1910.

OIL-GRAVEL-MACADAM.

The experiment at Boise, Idaho, was conducted by the Office of Public Roads in cooperation with the road commissioners of Ada County. At the request of the commissioners an engineer was sent to Boise for the purpose of making a survey of the proposed road and to draw up specifications for the work, which was afterwards begun under his supervision. After the work was well under way the engineer resigned and nearly five weeks elapsed before another man could be sent in his place. During this time no detailed cost data of the work had been kept, so that the following report includes only the work done by the second man in connection with the application of oil to the road.

This road is a continuation of Ninth Street running south from the Boise River and ending at Morris Hill Cemetery. Its total length is 7,262 feet, and for a distance of 5,163 feet it has a width of 16 feet, while for 2,099 feet the width is 20 feet. Beginning at the bridge which crosses the Boise River, the first 2,099 feet had been an old earth road composed of very fine soil, which became exceedingly dusty during the long dry spells that are of common occurrence in that locality. When work was begun on the section, the old road which was to serve as a subgrade was covered with dust for a depth of 6 inches. The subgrade should have been watered at this time and properly crowned, but this was not done. The No. 1 course was placed directly upon this dust bed and the shoulders were nothing more than dust heaps.

The foundation course of No. 1 stone was placed loose, upon the subgrade to a depth of 6 inches, filled with sand, and rolled with a 12-ton steam roller. This course consisted of river gravel ranging from 2½ to 1½ inches in diameter, and 50 per cent of it had been crushed.

Upon the foundation a wearing course of crushed gravel, ranging from 1½ inches to ½ inch in diameter, was placed loose to a depth of 2½ inches. Because of a delay in shipping the oil, the gravel was rolled and allowed to stand for some time before the oil was applied. The following description covers the work and cost data for it from this point on in the construction of an experimental section.

This section extends from station 51 + 63 north to station 68 + 34, which is 428 feet from the bridge crossing the Boise River. It is 1,671 feet in length and 20 feet in width, and is subjected to a considerable amount of heavy teaming traffic in addition to light horse-drawn and automobile traffic. Common labor was figured at $2 per day for this work, while the double team and driver cost $5 per day.

The wearing surface was first prepared to receive the oil by harrowing it until the coarse stone came to the surface, filling low spots and otherwise bringing the surface to a ½-inch crown. The oil, which was a heavy California residuum, shipped in a 6,500-gallon tank car from Port Richmond, Cal., was furnished under specifications drawn up by the office. It cost 2 cents per gallon f. o. b. Port Richmond, but the freight charges to Boise increased this cost to over 11 cents per gallon. Upon examination this oil showed the following properties:

TABLE 16.—*Analysis of asphaltic oil residuum*[1] *used in experiment at Boise, Idaho.*

Specific gravity 25°/25° C	0.998
Float test at 32° C. (time)	6′ 54″
Per cent of loss at 163° C., 5 hours (20 grams)	.90
Float test on residue[2] (as above)	12′ 20″
Per cent of bitumen insoluble in 86° B. paraffin naphtha	7.07
Per cent of fixed carbon	6.28
Per cent of bitumen soluble in CS_2, air temperature (total bitumen)	99.95
Organic matter insoluble	.04
Inorganic matter	.01
	100.00

This oil was heated in the tank car near the road at the gas company's siding, by the means of steam at 60 pounds pressure. The car was equipped with 5 lengths of 1½-inch pipe placed about one-fourth the way up from the bottom, which did not present sufficient heating surface to heat the oil satisfactorily, and a full week was required to empty the car, since the work was handicapped to a considerable extent by the cold weather. Because of these conditions it was never possible to apply the oil in as fluid a condition as desirable. The steam used for heating the oil was supplied from the boiler

[1] Viscous, sticky. [2] Very viscous, sticky; surface lustrous.

of the gas company. Considerable time was lost in attempting to pump the oil from the tank car to the distributing wagon and it was finally emptied in this wagon by gravity, after a pit had been dug sufficiently deep to bring the top of the tank wagon below the bottom of the car.

The distributing wagon consisted of a 500-gallon sheet-iron tank fitted with steam coils and mounted on a wagon body. It was fitted with a patented distributor which was operated by a man seated back of the tank. This distributor was built in three 2-foot sections so that the oil could be applied through a series of small holes for a width of either 2, 4, or 6 feet at one passage of the wagon. The distributing pipe was so arranged that it could be raised or lowered to any desired height above the road surface. It was admirably designed for the application of rather light fluid oils, but was not strongly enough constructed to apply the oil in question. A number of its parts were broken during operation and the work of application was thus delayed.

The oil was applied to the prepared road surface by means of this distributor at a temperature of but little over 100° C. at the rate of 1.75 gallons to the square yard. The wagon was drawn over the road by the steam roller. Application was not as uniform as could be desired because of the low temperature of the oil, a fact which also hindered its penetration into the wearing course. After the oil had been applied, sand was spread over the road surface, which was then rolled. As the rolling proceeded, the oil sweated to the surface in places and more sand was applied as occasion required. When finished, on October 8, the road presented a good appearance, with the exception of a surplus of sand. This, however, was allowed to remain in order to absorb the oil which it was expected would ooze to the surface for some time.

The cost data for this experiment are given in the following table:

TABLE 17.—*Materials and cost data for experiment at Boise, Idaho.*

Length of section	feet	1,671
Area of section	square yards	3,713
Sand per square yard	cubic yard	.035
Oil per square yard	gallons	1.75
Cost of harrowing wearing surface per square yard	cents	0.20
Cost of oil per square yard	do	3.50
Cost of freight and demurrage on oil per square yard	do	15.75
Cost of heating and applying oil per square yard	do	2.43
Cost of sand at the road per square yard	do	3.50
Cost of spreading sand per square yard	do	.20
Cost of rolling per square yard	do	3.25
Total cost per square yard	do	28.83
Total cost of entire section		$1,070.46

EXPERIMENTS AT WASHINGTON, D. C., 1910.

CONCENTRATED WASTE SULPHITE LIQUOR, SEMIASPHALTIC OIL EMULSION, AND OIL-CEMENT-CONCRETE.

SURFACE TREATMENT.

The roads selected for the experiments with concentrated waste sulphite liquor and semiasphaltic oil emulsion are located in the Agricultural Department grounds, Washington, D. C. They are trap-rock macadam, which was originally bound with screenings of soft limestone and, although subjected to only a moderate amount of light traffic, they became quite dusty in dry weather. The sulphite liquor and oil emulsion were used not only for the purpose of laying the dust, but also to act as surface binders.

EXPERIMENT NO. 1, SECTION NO. 1.—CONCENTRATED WASTE SULPHITE LIQUOR.

Section No. 1 connects Thirteenth and Fourteenth Streets and is the same section that was treated with concentrated waste sulphite liquor in 1909. A complete description of this experiment was published in Circular No. 92. At the beginning of spring the road was in good condition, but with this exception there was no evidence of previous treatment. It was decided to continue the application of concentrated waste sulphite liquor to this road during the year. Application of the material was therefore made from time to time as occasion required. Upon examination this sulphite liquor showed the following properties:

TABLE 17.—*Analysis of concentrated waste sulphite liquor*[1] *used in experiment No. 1.*

Specific gravity 25°/25° C.	1.265
Per cent of loss at 100° C., heated to constant weight	50.25
Per cent of total solids as residue	49.75
Per cent of ash[2]	6.94
Per cent of organic solids	42.81

This material was pumped from the barrels in which it was shipped into an ordinary watering cart by means of a rotary hand pump. It was then diluted with water to the desired strength and applied in the same manner as water. Six applications were made during the season and by this means the road was kept practically dustless and in excellent condition. Before each application the road was swept free from sticks, leaves, and other detritus with ordinary hand brooms. For this and the other surface-treatment experiments common labor was figured at $2 per day of 8 hours; a 300-gallon sprinkling cart, with one horse, at $5 per day; and a 500-gallon sprinkling cart, with two horses, at $7 per day. The section was 615 feet in length and 16 feet in width, making an area of 1,093 square yards. The materials and cost data for this experiment are given in Table 18.

[1] General characteristics, brown fluid, viscous, and sticky. [2] Light gray.

TABLE 18.—*Materials and cost data for experiment No. 1—Concentrated waste sulphite liquor.*

Date of application.	Strength of solution (per cent).	Binder (gallons per square yard).	Cost data (cents per square yard).		Total cost (cents per square yard).
			Binder.	Labor.	
Apr. 7	50	0.142	1.988	0.161	2.149
Apr. 8	50	.103	1.442	.120	1.562
May 20	$16\frac{2}{3}$	.046	.644	.103	.747
June 29	25	.091	1.274	.132	1.406
Aug. 25	$33\frac{1}{3}$	.123	1.722	.202	1.924
Oct. 5	$33\frac{1}{3}$	.165	2.310	.265	2.575
Total		.670	9.38	.98	10.36

Total cost of entire treatment, $113.23.

EXPERIMENT NO. 2, SECTION NO. 2.—SEMIASPHALTIC OIL EMULSION.

Section No. 2 is an extension of section No. 1, and connects Thirteenth and Twelfth Streets. It is 398.7 feet in length by 16.1 feet in width and has an area of 713 square yards. The condition of this road before treatment was not quite as satisfactory as that of section No. 1. The emulsion used in this experiment had been purchased the previous autumn and during the winter had been stored out of doors. During this time a certain amount of separation of the oil from the emulsifying agents had taken place in each barrel and it was found impossible to emulsify this separated oil, which floated to the top of the mixture in the sprinkling cart. This oil caused considerable trouble by clogging the sprinkler and, when applied to the road, produced soft, sticky places, which had to be sanded. In order to avoid this trouble, the watering cart was never completely emptied on the road, but the separated oil was run off on a vacant lot. Notwithstanding this trouble, the material as applied proved to be quite satisfactory and would undoubtedly have shown up to better advantage had it been used before the separation had taken place.

Because of the separation a fair sample of the original material could not be obtained for examination. The following analysis, however, shows the material which was actually applied to the road after the separated oil had been removed, but before water had been added:

TABLE 19.—*Analysis of semiasphaltic oil emulsion* [1] *used in experiment No. 2.*

Specific gravity 25°/25° C	0.962
Per cent of loss at 100° C., 5 hours [2] (20 grams)	19.94
Examination of residue:	
Per cent of organic matter soluble in CS_2, but insoluble in 86° B. paraffin naphtha	11.83
Per cent of fixed carbon	4.28
Per cent of material soluble in CS_2, air temperature	99.08
Organic matter insoluble	.81
Inorganic matter	.11
	100.00

[1] Fluid, sticky; piney odor.

[2] Semisolid, sticky.

This material was handled and applied in the same manner as the concentrated waste sulphite liquor previously described. After the third application the road was sanded in places where the oil had made the surface sticky. A thin asphaltic skin was gradually formed over the road, which gave it the appearance of a bituminous macadam road with a mosaic surface. The materials and cost data for this experiment are given in Table 20.

TABLE 20.—*Materials and cost data for experiment No. 2—Semiasphaltic oil emulsion.*

Date of application.	Strength of solution (per cent).	Binder (gallons per square yard).	Sand (cubic yards per square yard).	Cost data (cents per square yard).			Total cost (cents per square yard).
				Binder.	Sand.	Labor.	
Apr. 7	20	0.0540	....	0.756	....	0.161	0.917
Apr. 8	20	.0460	....	.644	....	.120	.764
Apr. 15	16⅔	.0300	0.0005	.420	0.05	.101	.571
May 20	8⅓	.0123	....	.172	....	.103	.275
June 29	11	.0225	....	.315	....	.132	.447
Aug. 25	11	.0222	....	.311	....	.202	.513
Total	....	.187	.0005	2.62	.05	.82	3.49

Total cost of entire treatment, $24.88.

EXPERIMENT NO. 3, SECTION NO. 3.—SEMIASPHALTIC OIL EMULSION.

Section No. 3 adjoins section No. 2 and runs south almost parallel to Twelfth Street. It is 750 feet in length, 15.7 feet in width, and has an area of 1,310 square yards. It was not in as good condition before treatment as section No. 2, because the surface was raveled in places and the coarse stone of the foundation was showing through. This road should have been reconstructed, but as no money was available for the purpose, it was decided to try to hold it together until the following year with surface applications of the same oil emulsion as used in experiment No. 2. The emulsion was applied to the surface, after it had been swept, in the same manner as described under experiment No. 2. The materials and cost data for this experiment are as follows:

TABLE 21.—*Materials and cost data for experiment No. 3—Semiasphaltic oil emulsion.*

Date of application.	Strength of solution (per cent).	Binder (gallons per square yard).	Sand (cubic yards per square yard).	Cost data (cents per square yard).			Total cost (cents per square yard).
				Binder.	Sand.	Labor.	
Apr. 7	20	0.0540	....	0.756	....	0.161	0.917
Apr. 8	20	.0300	....	.420	....	.120	.540
Apr. 15	16⅔	.0300	0.0005	.420	0.05	.101	.571
May 20	8⅓	.0123	....	.172	....	.103	.275
June 29	11	.0225	....	.315	....	.132	.447
Aug. 25	11	.0222	....	.311	....	.202	.513
Total	....	.171	.0005	2.39	.05	.82	3.26

Total cost of entire treatment, $42.71.

Experiment No. 4, Section No. 4.—Semiasphaltic Oil Emulsion.

Section No. 4 adjoins section No. 1 and runs south almost parallel to Fourteenth Street. It is 750 feet in length, 15.8 feet in width, and has an area of 1,317 square yards. The material used, the method of treatment, and the reason for treatment were the same as described under experiment No. 3. This section was in even worse condition than section No. 3 and received one more application of the emulsion than the former. The materials and cost data for this experiment are given in Table 22.

Table 22.—*Materials and cost data for experiment No. 4—Lime asphaltic oil emulsion.*

Date of application.	Strength of solution (per cent).	Binder (gallons per square yard).	Sand (cubic yards per square yard).	Cost data (cents per square yard).			Total cost (cents per square yard).
				Binder.	Sand.	Labor.	
Apr. 7	20	0.0540	....	0.756	....	0.161	0.917
Apr. 8	20	.0300	....	.420	....	.120	.540
Apr. 15	16⅔	.0300	0.0015	.420	0.15	.510	1.080
May 20	8⅓	.0190	....	.266	....	.103	.369
June 29	11	.0225	....	.315	....	.132	.447
Aug. 25	11	.0258	....	.361	....	.202	.563
Oct. 5	11	.0296	.0001	.414	.01	.216	.640
Total	....	.211	.0016	2.95	.16	1.45	4.56

Total cost of entire treatment, $60.06.

Experiment No. 5, Section No. 5.—Concentrated Waste Sulphite Liquor and Semiasphaltic Oil Emulsion.

Section No. 5 is a short stretch of macadam road constructed in 1909. It lies between the two wings of the new department building and connects an asphalt pavement in the department grounds with B Street SW. It is subjected to heavier teaming traffic than any of the other sections. Both the concentrated waste sulphite liquor and the oil emulsion previously described were used in the surface treatment of this road, as shown in Table 23. This section is 192 feet long. For a length of 177 feet it is 18 feet wide, while for the remaining 15 feet it narrows to 11 feet. Its total area is 372 square yards.

Table 23.[1]— *Materials and cost data for experiment No. 5—Concentrated waste sulphite liquor and semiasphaltic oil emulsion.*

Date of application.	Strength of solution (per cent).	Sulphite liquor (gallons per square yard).	Emulsion (gallons per square yard).	Cost data (cents per square yard).			Total cost (cents per square yard).
				Sulphite liquor.	Emulsion.	Labor.	
Apr. 7	50	0.106	....	1.484	....	0.161	1.645
Apr. 8	50	.139	0.067	1.946	0.938	.120	3.004
Apr. 20	21	.045	.022	.630	.308	.103	1.041
June 29	20	....	.134	....	1.876	.132	2.008
Aug. 25	11	....	.057	....	.798	.202	1.000
Oct. 5	11	....	.030	....	.420	.215	.635
Total	....	.290	.310	4.06	4.34	.93	9.33

Total cost of entire treatment, $34.71.

[1] In both the second and third applications the sulphite liquor and emulsion were mixed together, and this mixture was made up to the strength of the solution as indicated.

Experiment No. 6, Section No. 6.—Concentrated Waste Sulphite Liquor and Semiasphaltic Oil Emulsion.

Section No. 6 is a short stretch of macadam road constructed at the same time as section No. 5 in 1909. It constitutes a horseshoe approach leading from Twelfth Street to the east wing of the new Department of Agriculture Building. It is 255 feet long, and for a length of 212 feet it is 12 feet wide, while for the remaining 43 feet it is only 8 feet wide. Its total area is 321 square yards. This section was not subjected to enough traffic to keep it in good condition and in places the surface was loose and raveled. With the exception of the addition of some stone screenings, this section was treated in a manner quite similar to the treatment of section No. 5. The materials and cost data for this work are as follows:

Table 24.—*Materials and cost data for experiment No. 6—Concentrated waste sulphite liquor and semiasphaltic oil emulsion.*

Date of application.	Strength of solution (per cent).	Sulphite liquor (gallons per square yard).	Emulsion (gallons per square yard).	Screenings (cubic yards per square yard).	Cost data (cents per square yard).				Total cost (cents per square yard).
					Sulphite liquor.	Emulsion.	Screenings.	Labor.	
Apr. 7	50	0.200			2.800			0.161	2.961
Apr. 8	50	.081	0.039		1.134	0.546		.120	1.800
Apr. 11	50	.112		0.003	1.568		0.350	.508	2.426
May 20	21	.045	.022		.630	.308		.103	1.041
June 29	25	.100			1.400			.132	1.532
Aug. 25	33⅓	.176			2.464			.202	2.666
Oct. 5	33⅓	.153			2.142			.265	2.407
Total		.867	.061	.003	12.14	.85	.35	1.49	14.83

Total cost of entire treatment, $47.60.

Experiment No. 7, Section No. 7.—Concentrated Waste Sulphite Liquor and Semiasphaltic Oil Emulsion.

Section No. 7 is a horseshoe approach leading from Fourteenth Street to the west wing of the new Department of Agriculture Building. It corresponds in every way to section No. 6, but its surface was not quite so badly raveled and did not require screenings. It was treated in a manner quite similar to the treatment of section No. 6. This section is 352 feet in length and 11.8 feet in width, and has an area of 462 square yards. The materials and cost data for this experiment are given in Table 25.

TABLE 25.—*Materials and cost data for experiment No. 7—Concentrated waste sulphite liquor and semiasphaltic oil emulsion.*

Date of application.	Strength of solution (percent).	Sulphite liquor (gallons per square yard).	Emulsion (gallons per square yard).	Cost data (cents per square yard).			Total cost (cents per square yard).
				Sulphite liquor.	Emulsion.	Labor.	
Apr. 7	50	0.200	....	2.800	....	0.161	2.961
Apr. 8	50	.056	0.027	.784	0.378	.120	1.282
May 20	21	.045	.022	.630	.308	.103	1.041
June 29	25	.100	....	1.400	....	.132	1.532
Aug. 25	33⅓	.176	....	2.464	....	.202	2.666
Oct. 5	33⅓	.153	....	2.142	....	.265	2.407
Total	....	.730	.049	10.22	.69	.98	11.89

Total cost of entire treatment, $54.93.

SUMMARY OF EXPERIMENTS IN SURFACE TREATMENT AT WASHINGTON, D. C.

In comparing the results so far obtained from the preceding seven experiments it is, of course, necessary to take into consideration the condition of the road before treatment. When last inspected, on January 28, 1910, section No. 1, treated with the sulphite liquor, was in the best condition, but it should be remarked that this section was also in the best condition before treatment. In dry weather it presents a smooth, hard, well-bonded surface, which softens somewhat in wet weather, but never becomes actually muddy. Section No. 2, treated with the emulsion, was also in very fair condition when last inspected. In dry weather it presents a mosaic asphalt-like surface, which becomes slightly muddy under horse-drawn traffic in wet weather. For the amount used, the emulsion has so far produced very satisfactory results on sections 3 and 4, although neither of these sections is in what would be called excellent condition. Indications point, however, to the fact that the treatment which they have received will keep them in shape until they can be resurfaced. The mixture of sulphite liquor and emulsion used on sections Nos. 5, 6, and 7 did not prove quite as satisfactory as either material used alone, for it was found that the emulsion would, to a considerable extent, waterproof the road surface and prevent proper absorption of the sulphite liquor in later treatments.

OIL-CEMENT-CONCRETE EXPERIMENTS.

During the month of June, 1910, the Office of Public Roads, in cooperation with the District of Columbia, conducted a series of experiments on Meridian Place to determine the value of oil-cement-concrete as a road surface. Certain laboratory investigations had indicated that a mixture of Portland cement-concrete with residual petroleums might possibly be suitable for this purpose, and the following experiments were therefore made for the purpose of trying such mixtures in a thoroughly practical manner.

The part of the street selected for this work runs from Center Street east toward Fourteenth Street, a distance of 356.1 feet. It is 19.5

feet between gutters. The soil forming the subgrade is a coarse gravelly red clay, which after a rain becomes sticky on the surface, but remains firm below. The grade here is light and slopes toward the west. The north curb is 6 inches lower than the south curb, because of the fact that the District constructs its cross streets on the same grade as the main streets running north and south. Meridian Place is subjected to light traffic consisting of delivery wagons and pleasure vehicles. When the Office of Public Roads assumed supervision of the work, all grading had been completed and the curbs and gutters were in place. The cost data given in this report, therefore, include the cost only from this point on.

The foundation of the road was constructed in two courses, the first of which consisted of from ½-inch to 1½-inch broken stone placed to a depth of 5 inches loose upon the prepared subgrade. After this course had been rolled until firm with a 12-ton 3-wheel roller, screenings ranging from one-half inch to dust were applied, and the surface finished as in ordinary macadam road work. This method of construction was followed in the preparation of the foundation for all of the experiments.

Common labor for this work cost $1.50 per 8-hour day; foreman, $4; double teams, $4; a 5-ton tandem roller, $8; the 3-wheel roller, $12; and a "bug" concrete mixer, $4 per day. Stone and sand cost $2.50 per cubic yard delivered on the work. The oils and cement were donated, but their cost, including freight, is given in the cost data. The following experiments are given in the order in which they were conducted, while the corresponding sections are numbered consecutively from station 0 at Center Street running east.

Experiment No. 1, Section No. 7.—Fluid Residual Petroleum.

Section No. 7 extends from station 2 + 90.3 to station 3 + 56.1 and is 65.8 feet in length.

A stiff mortar of 1 part cement to 2 parts sand was first prepared by hand on a mixing board, and oil to the amount of 10 per cent by weight of the cement was then mixed with the mortar. The resulting mixture was laid over the prepared foundation to a depth of 1¼ inches and immediately covered with broken stone, similar to that used in the foundation, to a depth of 2½ inches. One side of the street was thus laid at a time and, when about 20 linear feet had been covered, an attempt was made to force the stone down into the mortar by rolling it with the 5-ton tandem roller. After the entire section had been rolled, it was found that the mortar had not been worked up into the voids of the stone course sufficiently. The road was, therefore, sprinkled and again rolled in the hope that a homogeneous mixture might thus be made. As this did not give the desired results, it was decided to grout the surface. A thin mortar of the same composition as that previously described was therefore pre-

pared, poured over the surface, and "broomed" in. This last process roughened up the surface somewhat, but otherwise the section was finished off in good condition by the application of a light coat of stone screenings running from one-half inch to dust. The characteristics of the oil used in this experiment are shown in Table 26.

TABLE 26.—*Analysis of petroleum residual oil used in experiment No. 1—Oil-cement-concrete.*

Specific gravity 25°/25° C	0.936
Viscosity at 50° C., Engler, 100 c. c., specific	44.1
Per cent of loss at 163° C., 5 hours [1] (20 grams)	1.26
Per cent of bitumen insoluble in 86° B. paraffin naphtha	1.99
Per cent of fixed carbon	3.40
Per cent of bitumen soluble in CS_2, air temperature (total bitumen)	99.92
Organic matter insoluble	.06
Inorganic matter	.02
	100.00

EXPERIMENT No. 2, SECTION No. 6.—FLUID RESIDUAL PETROLEUM.

This section extends from station 2+66 to station 2+90.3 and is 24.3 feet in length. The concrete aggregate for this experiment was composed of a 1½ : 2 : 4 mixture of cement, sand, and broken stone. The same oil as described in experiment No. 1 was added to the extent of 10 per cent by weight of the cement, after a mortar of the cement and sand had been prepared and before the broken stone was mixed in. The stone in this and the following experiments consisted of crushed trap ranging from 1½ inches to one-half inch in diameter.

The mixture was laid to a depth of 2½ inches over the prepared foundation and tamped until the mortar flushed to the surface and filled all voids. The resulting surface was not troweled, but was purposely left somewhat rough. While rolling an adjoining section the next day, the roller was run over this surface, causing slight cracks to develop in places. When last inspected, on January 31, however, no evidence of these cracks could be found.

EXPERIMENT No. 3, SECTION No. 5.—FLUID RESIDUAL PETROLEUM.

Section No. 5 extends from station 2+21 to station 2+66 and is 45 feet in length. In this and the following experiments the concrete was first prepared in a "bug" mixer. The sand or stone screenings, or both, as the case might be, were first placed in the mixer and the mixer was then driven to the stone pile, so that the cement and fine aggregate were mixed dry. Here the proper proportions of broken stone, water, and oil were added and, after the machine had been driven about 500 feet, the concrete was dumped upon a board. As it was not thoroughly mixed, it was then turned twice by hand before

[1] Fluid, very slightly sticky; too soft for consistency test.

shoveling it upon the road. After it had been placed in position, it was raked with the back of steel rakes to the desired grade and crown.

In this experiment the same oil as described in experiment No. 1 was used to the extent of 10 per cent by weight of the cement, and an attempt was made to use stone screenings in place of sand. The first batch was composed of cement, stone screenings, and broken trap rock, in the proportions 1½ : 2 : 4. As the voids of this mixture were not well filled, the proportions were changed to 1½ : 3 : 4 for the remainder of this section. Tamping failed to bring the mortar uniformly to the surface, and so the section was rolled with this object in view. As this did not produce the desired result, a cement grout similar to that used in experiment No. 1 was poured over the first 20 feet of this section adjoining section 6 and "broomed" in. The remaining 25 feet of the section were thoroughly tamped and troweled off with the back of a shovel.

Experiment No. 4, Section No. 4.—Fluid Residual Petroleum.

Section No. 4 extends from station 1 + 84 to station 2 + 21 and is 37 feet in length. As the screenings used in experiment No. 3 did not produce as dense an aggregate as desirable, it was thought well to replace a part of them with sand. The proportion of 1½ : 1 : 2 : 4 of cement, sand, screenings, and broken stone was then decided upon for this experiment. This aggregate was also used in the three succeeding experiments. The same oil as described in experiment No. 1 was used in this experiment to the extent of 15 per cent by weight of the cement. The concrete was laid and tamped in the manner previously described and finished off with the back of a shovel.

Experiment No. 5, Section No. 3.—Cut-back Petroleum Residue.

Section No. 3 extends from station 1 + 16 to station 1 + 84 and is 68 feet in length. This experiment was identical in every respect with experiment No. 4, except that a different oil product was used to the extent of 15 per cent by weight of the cement. The properties of this oil are given in Table 27.

Table 27.—*Analysis of cut-back petroleum residue* [1] *used in experiment No. 5.—Oil-cement-concrete.*

Specific gravity 25°/25° C	0.962
Flash point °C., open-cup method	35°
Burning point °C., open-cup method	170°
Per cent of loss at 163° C., 5 hours (20 grams)	13.23
Penetration of residue [2] (No. 2 N, 5 seconds, 100 grams, 25° C.)	116°
Per cent of bitumen insoluble in 86° B. paraffin naphtha	18.16
Per cent of fixed carbon	8.90
Per cent of bitumen soluble in CS_2, air temperature (total bitumen)	99.85
Organic matter insoluble	.12
Inorganic matter	.03
	100.00

After laying, no difference between this section and section No. 4 could be noticed, except that the surface of the latter was slightly lighter in color.

EXPERIMENT NO. 6, SECTION NO. 2.—CUT-BACK PETROLEUM RESIDUE.

Section No. 2 extends from station 0 + 43.6 to station 1 + 16 and is 72.4 feet in length. This experiment is identical with experiment No. 5, with the exception that the cut-back oil was used to the extent of 10 per cent by weight of the cement instead of 15 per cent.

EXPERIMENT NO. 7, SECTION NO. 1.—PLAIN CEMENT-CONCRETE.

Section No. 1 extends from station 0 + 4.2 to station 0 + 43.6 and is 39.4 feet in length. In this experiment the cement-concrete was prepared and laid in exactly the same manner as sections Nos. 3, 4, 5, and 6, except that no oil was used in the mixture. This was done for the purpose of comparing ordinary Portland cement-concrete with the oil-cement-concretes.

SUMMARY OF EXPERIMENTS WITH OIL-CEMENT-CONCRETE.

In the work described it was found that the concrete could be handled best when made sufficiently wet for the mortar to flush to the surface upon tamping, but not so wet that it would not hold its shape after being tamped. The best surface finish was obtained by troweling the wet concrete with the back of a flat No. 2 shovel until smooth and uniform.

All of the sections were closed to traffic for at least seven days after being laid and they were sprinkled with water daily during this time. A thin layer of sand was spread over the surface from station 0 + 4.2 to station 2 + 40 and a thin layer of stone screenings ranging from one-half inch to dust was spread from station 2 + 40 to station 3 + 56.

When last inspected, on January 31, all of these sections were in excellent condition, although the street was covered with a light coat of mud brought in from other roads. No important difference between the sections could be seen at that time and a considerable period of time will probably be required to determine what practical differences if any do exist. The materials and cost data for these experiments are given in Table 28.

TABLE 28.—*Materials and cost data of experiments with oil-cement-concrete at Washington, D. C.*

Experiment No.	Section No.	Description.			Quantity of material.					Cost data (cents per square yard).							Total cost—	
		Oil.	Length of section (feet).	Area of section (square yards).	Stone (cubic yards per square yard).	Screenings (cubic yards per square yard).	Sand (cubic yards per square yard).	Cement (cubic yards per square yard).	Oil (gallons per square yard).	Stone at mixer.	Screenings at mixer.	Sand at mixer.	Cement at mixer.	Oil at mixer.	Mixing and laying concrete.	Foundation and miscellaneous.	Cents (per square yard).	Entire section.
1	7	Fluid residual petroleum	65.8	142.6	0.063	....	0.027	0.015	0.534	15.75	....	6.75	14.18	4.01	24.20	52.52	117.41	$167.43
2	6	....do	24.3	52.6	.047	....	.024	.018	.640	11.75	....	6.00	17.01	4.80	23.05	52.52	115.13	60.56
3	5	....do	45.0	97.5	.047	0.036	....	.018	.640	11.75	9.00	....	17.01	4.80	23.05	52.52	118.13	115.18
4	4	....do	37.0	80.2	.047	.024	.012	.018	.960	11.75	6.00	3.00	17.01	7.20	23.05	52.52	120.53	96.67
5	3	Cut-back petroleum residue	68.0	147.3	.047	.024	.012	.018	.937	11.75	6.00	3.00	17.01	12.18	23.05	52.52	125.51	184.88
6	2	....do	72.4	156.9	.047	.024	.012	.018	.625	11.75	6.00	3.00	17.01	8.13	23.05	52.52	121.46	190.57
7	1	None	39.4	85.4	.047	.024	.012	.018	....	11.75	6.00	3.00	17.01	....	23.05	52.52	113.33	96.78

EXPERIMENTS AT NEW YORK, N. Y., 1910.

OIL-CEMENT-CONCRETE.

The experiments at New York City were conducted by the Office of Public Roads during the months of May and June, in cooperation with the Bureau of Engineering and Construction of the Borough of Richmond, New York City, for the purpose of ascertaining the value of oil-cement-concrete as a road material.

The road selected was that part of Innis Street at Elm Park Station, Staten Island, running east from Morning Star Road to John Street. This street is subjected to medium traffic, consisting of drays, delivery wagons, and automobiles. The oils for these experiments were donated by two oil companies, and the cement was furnished by four manufacturers through the Association of American Portland Cement Manufacturers. The Borough of Richmond, New York City, furnished labor, sand, and stone, while the Office of Public Roads paid the freight on both the oil and cement, and furnished supervision of the work.

The foundation for the wearing course of oil-cement-concrete was prepared by first picking and leveling the rough places of the old macadam surface. The old cobblestones were removed from the gutters and, after the curbing had been cut and reset in concrete, the gutters were relaid with oil-cement-concrete, leveled, and tamped solid. The old material was allowed to conform to the original surface, and no attempt was made to obtain a uniform crown in the foundation. The concrete surface was laid upon the foundation as nearly as possible 4 inches deep, but, owing to unevenness in the foundation and to the fact that the concrete was placed somewhat deeper in the gutters, it probably averaged about 4½ inches in thickness over the entire roadway, which was 32 feet wide between gutters.

A mixer of the old Smith type, driven by a small steam engine, was used in mixing the concrete. The desired mixture was obtained by placing the sand and cement in the machine and adding enough water to form a thin mortar. A bucket of oil was then added alternately with a barrow of stone, until sufficient oil for the batch had been consumed. The remainder of the stone was then added. As the mixer did not satisfactorily mix this last addition of stone with the mortar, a barrow of sand, cement, and oil matrix was taken from the front part of the machine and dumped into the batch again, and the mixing process was then continued. When thoroughly mixed, the concrete was dumped on a board, shoveled into barrows, and wheeled to the road. It was found that, as far as the mixture was concerned, it made no difference in what manner the material entered the machine, and the foregoing method was adopted as the quickest way of mixing a batch.

Each batch consisted of 1 barrel of cement, 8 cubic feet of sand, 16 cubic feet of crushed stone ranging from 1½ inches to ¾ inch in diameter, together with the proper amount of oil. The concrete was tried both wet and comparatively dry. It was found that a dry mixture was difficult to tamp in such a way as to flush the voids full of mortar. On the other hand, if very wet, it would not hold its shape and, upon drying out, the formation of hair cracks could be noticed. The best results were obtained by adding as much water as the concrete could contain without losing its shape when placed upon the road. The road was closed to traffic for seven days after completion.

For this work common labor cost $1.85 per 9-hour day; superintendent-foreman, $6; double teams, $4 per day; and the concrete mixer, $35 per week. Sand cost $1.15 per cubic yard delivered at the mixer, and broken stone $1.50 per cubic yard. Although the cement was donated, a cost of $1.32 per barrel delivered at the mixer is included in the cost data.

EXPERIMENT NO. 1, SECTION NO. 1.—FLUID RESIDUAL PETROLEUM.

Section No. 1 begins at Morning Star Road station 0 and runs east for a distance of 163 feet. In this experiment a fluid residual petroleum, similar to that employed in the experiments at Washington, D. C., was used to the extent of 15 per cent by weight of the cement. The mixture was spread with the back of a steel rake and tamped until the mortar flushed to the surface. The surface was not troweled, but was purposely left rather rough. Each morning the work of the preceding day was covered with about one-half inch of loose sand and was wetted down in order to keep the concrete moist.

The properties of the oil used in this experiment are given in Table 29.

TABLE 29.—*Analysis of petroleum residual oil used in experiment No. 1.*

Specific gravity 25°/25° C.	0.936
Viscosity at 50° C., Engler, 100 c. c., specific	45.1
Per cent of loss at 163° C., 5 hours[1] (20 grams)	.87
Per cent of bitumen insoluble in 86° B. paraffin naphtha	1.99
Per cent of fixed carbon	2.85
Per cent of bitumen soluble in CS_2, air temperature (total bitumen)	99.90
Organic matter insoluble	.08
Inorganic matter	.02
	100.00

EXPERIMENT NO. 2, SECTION NO. 2.—FLUID RESIDUAL PETROLEUM.

Section No. 2 extends from station 1+63 to station 2+40, a distance of 77 feet. This experiment was identical with experiment No. 1, except that another brand of Portland cement was used and that

[1] Fluid, very slightly sticky; too soft for consistency test.

the fluid residual petroleum was added to the extent of 10 per cent by weight of the cement. The only difference noted between this section and section No. 1 was that the concrete seemed to set somewhat faster in the former.

EXPERIMENT NO. 3, SECTION NO. 3.—CUT-BACK PETROLEUM RESIDUE.

Section No. 3 extends east from station 2 + 40 to station 3 + 40.5, a distance of 100.5 feet. In this experiment still another brand of Portland cement was used and a cut-back petroleum residuum was added to the extent of 18¾ per cent by weight of the cement. The first 40 feet of this section were laid in exactly the same manner as previously described, but the remainder did not receive the sand covering. For the last 20 feet the concrete was made very wet, lightly tamped, troweled with the back of a shovel, and floated with a straight edge from crown to curb. After a few days a number of hair cracks were noticed in the last 20 feet. The concrete "set up" slowly as compared with the two preceding sections.

The properties of the oil used in this experiment are shown in Table 30.

TABLE 30.—*Analysis of cut-back petroleum residue*[1] *used in experiment No. 5.*

Specific gravity 25°/25° C	0.957
Flash point, °C., open-cup method	34°
Burning point, °C., open-cup method	149°
Per cent of loss at 163° C., 5 hours (20 grams)	15.23
Penetration of residue [2] (No. 2 N, 5 seconds, 100 grams, 25° C.)	111°
Per cent of bitumen insoluble in 86° B. paraffin naphtha	17.44
Per cent of fixed carbon	8.20
Per cent of bitumen soluble in CS_2, air temperature (total bitumen)	99.84
Organic matter insoluble	.09
Inorganic matter	.07
	100.00

EXPERIMENT NO. 4, SECTION NO. 4.—CUT-BACK PETROLEUM RESIDUE.

Section No. 4 extends from station 3 + 40.5 to station 4 + 44, a distance of 103.5 feet. In this experiment a fourth brand of Portland cement was used with the cut-back oil to the extent of 18¾ per cent by weight. The work was quite similar to that described in experiment No. 3. Where the mixture was made wet and finished as in the latter part of section No. 3, cracks developed as before. One of these cracks extended across the entire width of the road at station 3 + 55. When this was noticed, the mixture for the last 15 feet of this section was made less wet and tamped hard before troweling it. Even under these conditions 2 short cracks about 3 feet in length developed. Only the first 10 feet of this section were covered with sand.

[1] Viscous, fluid, sticky; too soft for penetration determination. [2] Semisolid, sticky.

Summary of Experiments at New York, N. Y.

When last inspected, on January 21, the oil-cement-concrete work at New York did not appear as satisfactory as that done at Washington. The division line between each day's work was plainly apparent, and the entire surface was rather rough and uneven. Inspection was made shortly after a rain and the road appeared in somewhat better condition than when previously inspected during dry weather in October. Sections Nos. 1 and 2 were in better condition than the other two. On section No. 1 a crack, evidently due to a poor joint between two days' work, was noticed extending across the road at station 1 + 20. From station 1 + 48 to station 1 + 52 a number of cup-shaped depressions were noted, although the concrete at these places appeared sound. At station 1 + 52 another crack had developed across the road, but from this point on for a distance of 60 feet the surface was in excellent condition.

At station 1 + 63 no change in the surface was noted where section No. 2 begins. At station 2 + 18 a crack had formed across the road, but had been filled with dirt and sand so that it was hardly noticeable. At station 2 + 30 the road had been cut transversely for the purpose of laying a pipe, and the trench thus made had been filled merely with the loose material which had been taken out. From this cut a longitudinal crack was noticed extending to station 2 + 40.

On section No. 3 the surface from station 3 + 03 to station 3 + 20 was rather crumbly and could be dug into with a knife to some extent. From station 3 + 20 to station 3 + 40 the concrete was very crumbly, and in fact was scarcely better than ordinary macadam. The stone fragments of the concrete at this point could be readily removed with a pocketknife. This was the worst section of the four.

On section No. 4 three transverse cracks filled with dirt were noticed between stations 3 + 40.5 and 3 + 90. Between these stations the concrete was found to be rather crumbly. From station 3 + 90 onward this section was in better condition, but, while the concrete could scarcely be called crumbly, it could be readily scratched with a knife.

The materials and cost data for these experiments are given in Table 31.

TABLE 31.—*Materials and cost data of experiments with oil-cement-concrete at New York, N. Y.*

Experiment No.	Section No.	Description.			Quantity of material.				Cost data (cents per square yard).						Total cost—	
		Oil.	Length of section (feet).	Area of section (square yards).	Stone (cubic yards per square yard).	Sand (cubic yards per square yard).	Cement (cubic yards per square yard).	Oil (gallons per square yard).	Stone at mixer.	Sand at mixer.	Cement at mixer.	Oil at mixer.	Mixing and laying concrete.	Preparing foundation and miscellaneous.	Cents (per square yard).	Entire section.
1	1	Fluid residual petroleum	163	580	0.123	0.062	0.031	1.61	18.45	7.13	27.62	12.07	21.78	2.28	89.33	$518.11
2	2	....do	77	274	.123	.062	.031	1.07	18.45	7.13	27.62	8.02	21.78	2.28	85.28	233.67
3	3	Cut-back petroleum residuum	100.5	357	.123	.062	.031	1.88	18.45	7.13	27.62	24.44	21.78	2.28	101.70	363.07
4	4	....do	103.5	368	.123	.062	.031	1.88	18.45	7.13	27.62	24.44	21.78	2.28	101.70	374.26

EXPERIMENTS AT RIDGEWOOD, N. J., 1910.

OIL-CEMENT-CONCRETE.

During the months of April and May two experiments with oil-cement-concrete in the construction of bridge-floor surfaces were conducted at Ridgewood, N. J., in cooperation with the county highway engineer of Bergen County. These were the first practical experiments with oil-cement-concrete made by the office, and were quite similar to those conducted at New York and Washington, D. C., which have already been described in this circular.

In both of these experiments the old wooden bridge floors were replaced with Portland cement-concrete laid on iron sheathing and reinforced with "chicken wire." The concrete was laid 6½ inches thick at the center and tapered to 4½ inches at the sides, giving an average thickness of 5½ inches. Only the upper layer of from 1½ to 2 inches of this concrete contained oil.

For this work common labor cost $2.25 per 9-hour day, and foreman $6 per day. Cement cost 37 cents per bag, sand 80 cents per cubic yard, and crushed stone $2.50 per cubic yard, delivered on the work.

Experiment No. 1.—Fluid Residual Petroleum.

The bridge on which this experiment was tried is on Paramus Road, crossing Saddle River. It is 37 feet in length and 19 feet in width, with a floor surface of 75 square yards.

The oil-cement-concrete surface was placed continuously with the rest of the concrete in the following manner: After a few batches of the ordinary concrete had been laid and tamped, and while it was still wet, a batch of the oil-cement-concrete was prepared and placed upon the surface to a depth of from 1½ to 2 inches. It was then tamped until the mortar flushed to the surface. By this means the two layers set together in a single course.

The oil-cement-concrete was mixed by hand upon a mixing board and shoveled into place. It was composed of Portland cement, bank sand, and crushed trap rock, ranging from three-fourths inch to one-fourth inch in diameter in the proportion of 1:2:4. The sand and cement were first mixed into a stiff mortar, to which was added a fluid residual petroleum to the extent of 15 per cent by weight of the cement. The stone was next added and mixed in. After the concrete had been placed and tamped, one-half of the surface was covered with a thin coating of sand and one-half with stone screenings. The bridge was closed to traffic for 10 days and during that time the surface was kept damp by sprinkling it each day with water. After the concrete had set, it was given a light surface treatment of the same oil at the rate of one-eighth gallon per square yard and sufficient sand was applied to take up any excess of oil.

The properties of the oil used in this experiment are given in Table 32.

TABLE 32.—*Analysis of petroleum residual oil used in experiment No. 1.*

Specific gravity 25°/25° C	0.937
Viscosity at 50° C., Engler, 100 c.c., specific	41.1
Per cent of loss at 163° C., 5 hours[1] (20 grams)	1.10
Per cent of bitumen insoluble in 86° B. paraffin naphtha	2.16
Per cent of fixed carbon	3.40
Per cent of bitumen soluble in CS_2, air temperature (total bitumen)	99.94
Organic matter insoluble	.03
Inorganic matter	.03
	100.00

EXPERIMENT NO. 2.—CUT-BACK PETROLEUM RESIDUE.

The bridge on which this experiment was tried is on Harrison Avenue crossing Hohokus River. It is 25 feet in length and 37 feet in width, with a floor surface of 103 square yards.

This experiment was practically identical with experiment No. 1, with the exception that in place of the fluid residual petroleum a cut-back petroleum residue was used to the extent of 18 per cent by weight of the cement.

The properties of this product are shown in Table 33.

TABLE 33.—*Analysis of cut-back petroleum residue[2] used in experiment No. 2.*

Specific gravity 25°/25° C	0.962
Per cent of loss at 163° C., 5 hours (20 grams)	13.38
Penetration of residue[3] (No. 2 N, 5 seconds, 100 grams, 25° C.)	111°
Per cent of bitumen insoluble in 86° B. paraffin naphtha	18.05
Per cent of fixed carbon	8.55
Per cent of bitumen soluble in CS_2, air temperature (total bitumen)	99.85
Organic matter insoluble	.12
Inorganic matter	.03
	100.00

This oil was not applied to the finished concrete surface, as in experiment No. 1, but later Harrison Avenue was oiled by the town with a light petroleum product and at that time the bridge surface was also oiled.

SUMMARY OF EXPERIMENTS AT RIDGEWOOD, N. J.

When last inspected, on January 21, both of these bridge surfaces were in good condition. The Paramus Road Bridge showed a rather rough mosaic surface, free from cracks. The covering of oil, sand, and screenings had been largely pushed to the sides and a considerable amount of mud had been deposited upon the surface by passing

[1] Fluid, very slightly sticky; too soft for consistency test.
[2] Viscous, fluid, sticky; too soft for penetration determination.
[3] Semisolid, sticky.

vehicles. The approach at the west end had been badly rutted by heavy traffic and the beginning of the concrete had spalled somewhat at this point because of the impact of vehicles. There was no evidence of cracks, but two small spots appeared rather soft when scratched with a knife. The Harrison Avenue Bridge was in excellent condition when inspected at this time. An oil-earth mat about three-sixteenths inch thick was evenly distributed over the surface and there was no evidence of cracks where this mat was scraped away. At these places, however, the concrete appeared somewhat soft under a knife. Both approaches were in excellent condition and no spalling was noticed at the juncture of the road and bridge surfaces. Apparently the traffic over this bridge is not as heavy as over the Paramus Road Bridge.

It was a difficult matter to obtain the exact itemized cost data for these experiments because of the fact that the foundation and the wearing surface were laid almost simultaneously. The following table will, however, show the approximate cost of the wearing surface of oil-cement-concrete:

TABLE 34.—*Materials and cost data of experiments with oil-cement-concrete wearing surface at Ridgewood, N. J.*

Experiment No.	Description.			Quantity of material.						Cost data (cents per square yard).							Total cost—	
	Oil.	Length of section (feet).	Area of section (square yards).	Stone (cubic yards per square yard).	Sand (cubic yards per square yard).	Cement (cubic yards per square yard).	Oil in concrete (gallons per square yard.)	Oil in surface treatment (gallons per square yard).	Screenings (cubic yards per square yard).	Stone on work.	Sand on work.	Cement on work.	Oil in concrete on work.	Oil in surface treatment on work.	Screenings on work.	Labor.	Cents (per square yard).	Entire surface.
1	Fluid residual petroleum.....	37	78	0.042	0.021	0.010	0.500	0.141	0.006	10.50	1.68	9.99	3.75	1.06	0.99	18.11	46.08	$35.94
2	Cut-back petroleum residue..	37	103	.034	.017	.008	.544	....	....	8.50	1.36	7.99	7.07	....	....	16.55	41.47	42.71

SUPPLEMENTARY REPORT OF EXPERIMENTS MADE AT YOUNGSTOWN, OHIO, IN 1909.

SLAG, SLAG AND LIME, SLAG AND WASTE SULPHITE LIQUOR PREPARATION, AND SLAG AND TAR.

The original report of these experiments is to be found in Circular No. 92 of this office. Seven experiments were made with blast-furnace slag in road construction. Of these, three were straight blast-furnace slag; one blast-furnace slag bound with open-hearth slag screenings; and one each of blast-furnace slag and lime, blast-furnace slag and sulphite liquor preparation, and blast-furnace slag and refined coke-oven tar. All materials other than the blast-furnace slag were used as binders for the wearing surface. The sections were last inspected January 27, 1911, about 18 months after construction. The weather was rainy and during previous months there had been a succession of frosts and thaws.

Experiments Nos. 1, 2, and 3.—Blast-Furnace Slag.

In experiment No. 1 crushed and screened blast-furnace slag had been laid in courses in exactly the same manner as crushed and screened rock for ordinary macadam construction. In experiment No. 2 the road consisted of a single course of crushed slag ranging from three-fourths inch to 3½ inches in diameter, while in experiment No. 3 the foundation consisted of unscreened fragments ranging from 3½ inches to dust, together with the wearing course of material similar to that used in experiment No. 2. When inspected just after a thaw, the first experiment showed to advantage in comparison with the other two. The surface, while not as firmly bound as some of the sections in which a binder other than blast-furnace slag screenings had been used, was in excellent condition. In experiments Nos. 2 and 3 the center of the roadway had been quite badly raveled by horses' hoofs, but little difference between the two sections of road was to be noticed, except that in experiment No. 2 a rather soft spot had developed in the center of the road at the middle of the section.

Experiment No. 4.—Blast-Furnace Slag—Open-Hearth Slag Screenings.

The section treated in this experiment was at the time of inspection undoubtedly superior to any of the others, with the exception of the tar-slag section. The surface was very firmly bonded and could not be dug into with a knife, except in a number of small spots from 2 to 4 inches in diameter, where the surface was soft and powdery. These spots were scattered irregularly over the road to the extent of 7 or 8 to each 100 linear feet and were evidently caused by the presence of a few soft, crumbly fragments of blast-furnace

slag. With this exception the entire surface appeared almost as solid as Portland cement-concrete. On one side of this section, about 50 feet from the northern end, the earth shoulder had settled and sloughed away for a distance of about 35 feet, and the edge of the road at this place had been cut back by traffic for a distance of 6 inches. The trouble can undoubtedly be attributed to a fresh fill, which was not consolidated sufficiently before the road was constructed. This place is to be repaired by building a crushed-slag shoulder.

Experiment No. 5.—Blast-Furnace Slag Screenings and Lime.

The section treated in this experiment was somewhat raveled and scarcely better than those described under experiments Nos. 2 and 3. During construction it seemed that this section would prove more satisfactory than any of those bound with plain blast-furnace slag screenings and during the past summer it actually proved somewhat more satisfactory. The open winter, however, showed experiment No. 1 up to better advantage.

Experiment No. 6.—Blast-Furnace Slag and Waste Sulphite Liquor Preparation.

The section treated in this experiment was in good condition and showed a fairly well bonded surface. This section was in slightly better condition than that described under experiment No. 1, but it was not as well bonded as the section described under experiment No. 4.

Experiment No. 7.—Blast-Furnace Slag and Refined Coke-Oven Tar.

The section treated in this experiment showed up to better advantage than any of the others at the time of inspection. The surface was perfectly bonded and presented a rather mosaic appearance. Although the road at this point had been constructed on a fresh fill which had settled somewhat since, the tar slag surface showed no evidence of having cracked when adjusting itself to this settlement.

SUPPLEMENTARY REPORT OF EXPERIMENTS MADE AT ITHACA, N. Y., IN 1909.

TAR, OIL, ARTIFICIAL ASPHALT PREPARATIONS, ROCK ASPHALT, BRICK, CEMENT AND SLAG.

A full report of these experiments is to be found in Circular No. 92 of this office. In the following report of an inspection made on November 2, 1910, no description of the work will be included, and for such information reference should be made to the abovementioned circular.

Experiment No. 1.—Refined Coal Tar—Penetration Method.

When last inspected this section was in excellent condition and showed a smooth, well-bonded surface.

Experiment No. 2.—Refined Coal Tar—Mixing Method.

This section showed a mosaic surface not quite as smooth as experiment No. 1, but evidently less slippery. Eight small pot holes ranging from 8 inches to 2 feet in diameter had developed since construction, owing probably to segregation of the aggregate during the mixing process. One of these holes was located at station 3+05, one at station 3+50, two at station 3+63, three at station 3+70, and one at station 3+72. During the fall of the year these holes had been cut out for a depth of 2 inches with vertical sides, and all loose material had been removed. They were then painted with the hot tar, refilled with a mixed tar aggregate, tamped, painted again with tar, and finished off with a dressing of stone chips. The total cost of this work amounted to 0.026 cent per square yard for the section.

Experiment No. 3.—Artificial Oil-Asphalt—Mixing Method.

This section was in excellent condition. The grade is, however, too low where it adjoins the brick section and should be raised. This will probably be done during the present year.

Experiment No. 4.—Artificial Oil-Asphalt—Mixing Method.

This section was in good condition, but the surface was apparantly not as homogeneous as that of the preceding experiment. The grade at this point was too low where it adjoins the ash-cement-concrete section and will have to be raised.

Experiment No. 5.—Refined Semiasphaltic Oil—Penetration Method.

This section was in very fair condition, but appeared somewhat soft in places. No raveling had occurred, however.

Experiment No. 6.—Semisolid, Refined, Semiasphaltic Oil—Penetration Method.

This section was in good condition, but the surface was somewhat rough, owing probably to the fact that no paint coat had been applied. The surface was well bonded.

Experiment No. 7.—Refined Water-Gas Tar—Penetration Method.

This section, also, was in good condition. An excess of tar was, however, present on the surface, which plainly showed the marks of wheels and horses' hoofs.

Experiment No. 8.—Refined Semiasphaltic Oil—Penetration Method.

This section was in fair condition, but showed evidence of having bled considerably during summer weather. This was due to the fluidity of the binder and to the excessive amount which was undoubtedly used. In spite of the fact that stone screenings had been applied during the summer, the surface was somewhat soft and showed the calk marks of horses' shoes.

Experiment No. 9.—Refined Water-Gas Tar and Slag—Penetration Method.

This section was in very good condition and appeared better than experiment No. 7, in which a lighter grade of the same tar had been used. There was no evidence of bleeding and the surface did not show marks of traffic.

Experiment No. 10.—Kentucky Rock Asphalt.

The western half of this section was in excellent condition and was considerably better than the eastern half. This indicates that it is preferable to lay the material in two courses rather than one. The whole section had the general appearance of a sheet asphalt pavement, but on the eastern half the surface was somewhat rough and in four spots about 2 feet in diameter four depressions where the coarse stone was showing through were observed. This was due to the fact that some of the rock asphalt had been cut up and picked out by traffic. Slight repairs will probably be needed on this section during the coming summer.

Experiment No. 11.—Open-Hearth Slag—Lime.

This section appeared very satisfactory as compared with the ordinary macadam on a continuation of the road which had been constructed at about the same time and which had raveled considerably since. There was no sign of raveling here, but the surface was not as well bonded as the section at Youngstown, in which open-hearth slag screenings had been used.

Experiment No. 12.—(a) Cement-Concrete; (b) Bituminous-Surfaced Cement-Concrete.

(*a*) When inspected on September 9, 1910, the straight cement-concrete section was in fair condition, but presented a rather rough and uneven surface, due evidently to the method of laying. There was only one small crack about 8 feet long in this entire section. It was decided to cover this section with a bituminous mat in the same manner as in experiment No. 12*b*. This was done before the last inspection on November 2 in the following manner:

The surface was first thoroughly cleaned by sweeping, after which the hot bituminous binding material was applied by pouring from

buckets at the rate of three-fourths of a gallon per square yard. While the bitumen was still hot, stone screenings ranging from one-fourth inch to one-half inch in diameter were applied in sufficient quantity to take up all excess of bitumen. A number of bituminous binding materials were applied to this section. The character of these materials is indicated by reference to Circular No. 92 in the cost data for this work given in Table 35.

(*b*) This section was in better condition than that treated in experiment No. 12*a*, but the greater part of the bituminous surface had worn away and it was therefore treated again in the same manner, as described under experiment No. 12*a*. The cost and materials data for this work are to be found in Table 35.

Experiment No. 13.—Ash-Cement-Concrete.

This section was in excellent condition, better indeed than any of the other cement-concrete sections. It was quite smooth and hard, and no cracks had developed. During the month of October, this section was given a bituminous surfacing in the same manner as described under experiment No. 12. The cost data for this work are shown in Table 35.

Experiment No. 14.—Brick.

At the time of inspection all of the brick sections were in excellent condition and showed but little effect of wear, since the thin grouting of cement had not entirely worn away.

Table 35.—*Materials and cost data for bituminous surface on cement-concrete sections, Ithaca, N. Y.*

Experiment No.	Section No.	Description.				Quantity of material.		Cost data (cents per square yard).			Total cost—	
		Wearing surface.	Bitumen.	Length of section (feet).	Area of section (square yards).	Screenings (cubic yards per square yard).	Binder used in paint coat (gallons per square yard).	Screenings at siding.	Binder.	Heating and applying binder and cleaning surface.	Cents (per square yard).	Entire section.
13	13	Ash-cement-concrete.	Refined semiasphaltic oil (Table 11, Circular 92).	35	62	0.026	0.57	3.95	3.99	3.08	11.02	$6.83
12*b*	14	Cement-concrete	......do	30	53	.026	.57	3.95	3.99	3.08	11.02	5.84
12*a*	15	......do	......do	90	160	.026	.57	3.95	3.99	3.08	11.02	17.63
12*a*	15	......do	Heavy refined coal tar (Table 5, Circular 92).	157	279	.026	.57	3.95	4.85	3.08	11.88	33.15
12*a*	15	......do	Heavy refined water-gas (Table 12, Circular 92).	142	252	.026	.57	3.95	3.99	3.08	11.02	27.77
12*a*	15	......do	Semisolid, refined, semiasphaltic oil (Table 9, Circular 92).	55	98	.026	.57	3.95	3.99	3.08	11.02	10.80
12*a*	15	......do	Heavy refined coal tar (Table 5, Circular 92).	21	37	.026	.57	3.95	4.85	3.08	11.88	4.40

SUPPLEMENTARY REPORT OF EXPERIMENTS MADE AT NEWTON, MASS., IN 1908.

ASPHALTIC PREPARATIONS, TAR PREPARATIONS, RESIDUAL OIL, AND MOLASSES-OIL-LIME.

These experiments are described in Circular No. 90, and the report of an inspection of the roads made on July 22, 1909, was published in Circular No. 92. The work was again inspected on August 19, 1910, after a heavy rain, and the following report was made:

Experiments Nos. 1, 2, 3, 4, 5, 6, and 7.—Asphaltic Preparation—Mixing Method.

These sections were in practically the same condition as when inspected in 1909. In sections Nos. 1 and 2 the surface is somewhat worn, but fairly well bonded. A number of spots which had failed had been patched with a mixture of oil and sand or gravel. Most of these patches were in the center of the road. Section No. 2 was in slightly better condition than No. 1 and section No. 3 was in better condition than the other two, with the exception of a spot about 2 feet in diameter about the middle of the section on the outer side of a curve. A few patches had been made at the western end of this section. Section No. 4 was well bonded and no repairs had been required, but the surface was somewhat rough since all of the tarred-sand dressing had been worn away and removed by traffic. Sections Nos. 5, 6, and 7 were in uniformly good condition.

Experiment No. 8.—Residual Oil—Mixing Method.

The surface of section No. 8 was loose in patches and could be easily dug into with a knife. At the intersection with Langdon Street it had raveled slightly. No repairs had been made on this section.

Experiments Nos. 9 and 10.—Refined Water-Gas Tar—Mixing Method.

Both of these sections were in almost perfect condition; they were smooth and so well bonded that it was practically impossible to dig into the wearing surface with a pocketknife. Section No. 10 presented a particularly satisfactory mosaic surface.

Experiment No. 11.—Molasses-Oil-Lime.

The surface of the molasses-oil-lime section was rather rough when inspected, and muddy at the sides. It was somewhat raveled in places, but was for the most part well bonded.

SUPPLEMENTARY REPORT OF EXPERIMENT MADE AT INDEPENDENCE, KANS., IN 1908.

OIL-ASPHALT IN THE CONSTRUCTION OF AN EARTH-ASPHALT ROAD.

The original report of this experiment is to be found in Circular No. 90, while the report of an inspection made on February 19, 1910, is contained in Circular No. 92. The road was again inspected on February 20, 1911, during cold, sleety weather, and the following results were reported:

That portion of the work on Minnehaha Street, where the soil is decomposed shale and argillaceous sandstone, was in good condition, free from ruts and fairly smooth. But little mud was noticed on this section, although its general appearance was that of an ordinary earth road. Tonopah Street, composed of gumbo and buckshot clay, was not in as good condition as Minnehaha Street and was quite muddy, especially the western block, where the mud was from 3 to 4 inches deep. A resident on this street reported that no repairs had been made since the road was constructed. During dry weather the entire road has been in good condition since construction.

SUPPLEMENTARY REPORT OF EXPERIMENTS MADE AT GARDEN CITY, DODGE CITY, BUCKLIN, AND FORD, KANS., IN 1908.

SAND-CLAY.

The original report of these experiments is to be found in Circular No. 90, and the report of an inspection during 1909 appears in Circular No. 92. The following is a report of inspection made during 1910:

Experiment at Garden City.

An inspection on December 14, 1910, of the sand-clay road at Garden City showed the road to be in fair condition with the following exception. In this experiment a local gypsum clay was mixed with the natural sandy soil. For a distance of 200 feet the road had broken through in places, forming chuck holes. The holes occur mainly in the wheel tracks, but some extend entirely across the road. On the rest of the road no ruts have developed and very little dust has been formed by traffic. It is nearly as hard as macadam and well bonded, with the exception of a few spots which will probably develop into chuck holes unless they are repaired in the near future. The road is scarcely wide enough to accommodate the traffic to which it is subjected and in places along the shoulders the sand-clay surface has been sheared off by the wheels of wagons turning out to pass each other. Maintenance of this road has been entirely neglected since its construction. Its present condition seems to indicate that dry weather has had more to do with its failure in places than heavy traffic.

Experiment at Dodge City.

In the work at Dodge City a clay silt obtained from an old irrigation ditch was mixed with a sandy soil similar to that encountered at Garden City. When inspected on December 13, 1910, the condition of the road varied in places from poor to good. Sections from 200 feet to 400 feet in length were quite satisfactory, but in other sections ruts had developed to a depth of 3 or 4 inches, and numerous chuck holes had been formed where the sand-clay surface had been reduced in thickness to such an extent that it was unable to sustain the weight of traffic. The portion of this road in Dodge Township, about one-fourth mile in length, was in poor condition, while the balance of the road could be called fair with the exception of the short sections above mentioned. The entire road was reported as being in good condition until the fall of 1910, and no repairs were made. The cause of its partial failure is undoubtedly due to a long-continued dry spell, for practically no rain had fallen for a year preceding the inspection. The road naturally became very dusty during this period and much of the sand-clay mixture was worn away. The southern end of the road outside of Dodge Township had been recently repaired to some extent by the addition of fresh material where needed, and it is evident that careful and constant maintenance will be required to keep the road in good condition from now on.

Experiment at Bucklin.

In this work a buckshot clay was mixed with a sandy soil. When inspected on December 15, 1910, this road had much the same appearance as that at Garden City. The sand-clay surface had broken through in a number of places and chuck holes had been formed. It was not, however, in as bad condition as the former road and was not rutted as deeply. The greater part of the surface was hard and smooth, and practically free from dust. Scarcely anything has been done in the way of maintenance since the road was constructed, with the exception of applying a few loads of new material at the approach to the bridge. If the chuck holes were repaired in a similar manner, the road could be put in good condition.

Experiment at Ford.

In this experiment a short section of road forming the southern approach to a bridge crossing the Arkansas River was graded and a sedimentary clay was added. When inspected on December 15, 1910, the road for about 350 feet was in excellent condition; it was hard, smooth, and practically free from ruts. The entire road was in better condition than any of the other experimental sand-clay roads, although no repairs had been made since construction. Very little dust was in evidence on the road surface.

SUPPLEMENTARY REPORT OF AN EXPERIMENT MADE AT BOWLING GREEN, KY., IN 1907.

KENTUCKY ROCK ASPHALT.

The original report of this experiment is to be found in Circular No. 89, the report of an inspection made during January, 1909, in Circular No. 90, and the report of an inspection made during the latter part of May, 1909, in Circular No. 92. On December 21, 1910, this road was again inspected. For 10 days previous to the inspection there had been light rains alternating with freezing weather. The temperature was about 28° F. at the time of inspection.

The entire section was smooth and hard, except as noted below. The cross section was well maintained; and the surface rang sharply under the blows of horses' hoofs. The city engineer stated that the road had been giving entire satisfaction and that no work had been done on it since its construction. Over the eastern half of the road, along each side and about 2 feet from the edge of the metaling, one and sometimes two shallow ruts about one-half inch deep and from 3 to 4 inches wide were in evidence. These indicate that the shoulders are insecure at this section.

About 100 feet from the eastern end, and half way toward the crown, one small cup hole had developed, in which stones could easily be loosened. Elsewhere there was no indication of loose material. The thin dust coat that gave the surface a general appearance of sheet asphalt had been worn away and in three places the underlying limestone was exposed. This stone was, however, thoroughly bonded and showed no indications of raveling.

The surface was everywhere hard and well compacted, and a small specimen of the rock asphalt when dug up and warmed in the hand showed that the bitumen still had considerable life.

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Issued July 18, 1911.

U. S. DEPARTMENT OF AGRICULTURE,

OFFICE OF PUBLIC ROADS—CIRCULAR No. 95.

LOGAN WALLER PAGE, DIRECTOR.

SPECIAL ROAD PROBLEMS IN THE SOUTHERN STATES.

BY

D. H. WINSLOW,

Superintendent of Road Construction, Office of Public Roads.

WASHINGTON:
GOVERNMENT PRINTING OFFICE
1911.

LETTER OF TRANSMITTAL.

United States Department of Agriculture,
Office of Public Roads,
Washington, D. C., April 24, 1911.

Sir: I have the honor to transmit herewith the manuscript of a circular by Mr. D. H. Winslow, a superintendent of road construction in this office, entitled "Special Road Problems in the Southern States." Publications of this specific character should have a great interest for the road builders in the section concerned, and it is hoped that much good may be derived from them. I therefore respectfully request that this manuscript be issued as Circular 95 of this office.

Respectfully,

Logan Waller Page, *Director.*

Hon. James Wilson,
Secretary of Agriculture.

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SPECIAL ROAD PROBLEMS IN THE SOUTHERN STATES.

INTRODUCTION.

While the general principles of road construction are nearly the same all over the United States, it will be found necessary to modify them somewhat, owing to climatic conditions, difference in the road materials available, and numerous varying local conditions. Problems will be encountered in the Northern States, owing to frost action and severe winters, that do not concern the southern road builders, and in turn the northern builders do not have to contend with tropical vegetation or the scarcity of free labor. There are certain road problems confined to the Southern States, and it is with these particular cases that this circular will deal, rather than with the general road problems.

It will be the aim of this publication to deal as concisely as possible with such difficulties and to offer a simple treatment of them by the use of local materials and labor.

FLOODED ROADS AND FORDS.

At certain seasons of the year, in some localities, there are roads that are entirely covered with water from 1 to 10 feet deep, and for a distance varying from a few hundred feet to more than a mile. Such conditions are found in the eastern Carolinas, and in southern Georgia, Alabama, Mississippi, Florida, and other States.

At such times, travel is practically cut off or confined to horseback riding, with a heavy loss to the community. Education is at a standstill; medical service is limited and irregular; church attendance becomes impossible; the mails are delayed, if not entirely abandoned; fire protection is cut off; and life on the farm becomes one of isolation and hardship. This is one of the conditions that this circular seeks to relieve by making the road passable 12 months in the year at a nominal cost.

As in other cases, the trouble should be traced to its source, but here, even when the cause is ascertained, the road builder is little better off, for the cause for such conditions hardly ever originates on the road itself. It is quite likely to be a choked channel on private

land, a swollen stream overflowing its banks, or a large drainage area emptying over a small area, which limited funds will not suffice to remedy, even if all the legal objections can be overcome.

FIG. 1.—Ford on a main road in South Carolina.

The real problem consists in doing the necessary work on the road itself without damage to the property on either side In some cases

FIG. 2.—A plank bridge in South Carolina one-half mile long.

a long bridge has been built, but such a bridge is expensive in its construction and is a constant item of maintenance. For most places, indeed, its cost is prohibitive.

To make a deep fill, with the necessary culverts, would also require a large financial outlay, especially since the slopes would require heavy facing to prevent sliding at flood season.

The growth of vegetation is so rapid in the South that clearance of channels, if permitted by the abutters, would be of little value unless systematically done at frequent intervals. There is, however, scarcely a section in the South where these conditions exist that either timber, brick, stone, or sand can not be obtained.

The first solution to the problem lies, then, in the use of timber for making the flooded sections passable, so that, for example, the engine of an automobile may be kept dry while going over the road.

On the downstream side of the road logs are placed parallel to the road in the form of a pyramid, with the top of the upper log set as high as the usual water level on the road. The bottom logs are held in place by either sinking them in a shallow trench or by driving heavy stakes. The logs are set at the extreme limits of the traveled way. Large-sized logs are used and the largest are placed in the base of the pyramid. These logs lie end to end except that space is left to

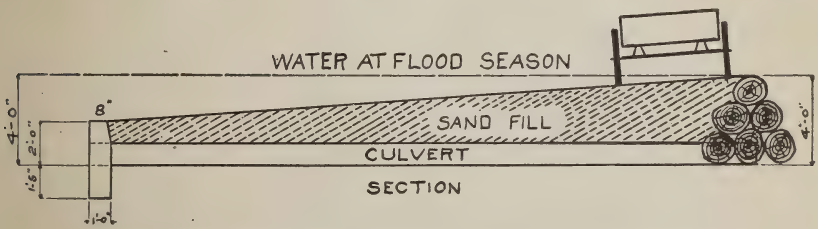

FIG. 3.—Crosscut view showing the method of draining a flooded road with logs.

permit a culvert with a head wall to pass through. The purpose of this culvert will be explained later. Sand is dumped against the logs on the side toward the traveled way until it is level with the top log and wide enough for a vehicle to travel on. The logs act as a retaining wall, or as a dam, and practically all sediment is retained, so as to form a gradual slope from the top of the logs to the opposite side of the road. By driving close to the logs a wagon or automobile encounters but a few inches of water. After the flood season and as the water recedes, the purpose of the culvert is apparent. The logs and sand act as a dam and, without the culvert, would keep the land flooded on the side of the road opposite the logs.

A culvert is placed at right angles to the road at the natural grade of the ground and protected with head walls at both ends. As the water recedes, it runs away from the logs down the incline to the inlet of the culvert and through this under the road. Every flood adds sediment and compacts the material.

If stone, brick, or sand can be had, a more permanent structure can be obtained by making it of concrete, brick, stone, or cement

mortar. If stone is the only available material, it is necessary only to lay the stone, like a wall, parallel to the road, similar to the arrangement of the logs as shown in figure 3. Where brick is used, the top of the wall should be at least 8 inches thick, while the thickness at the base depends upon the height of the wall. In some sections con-

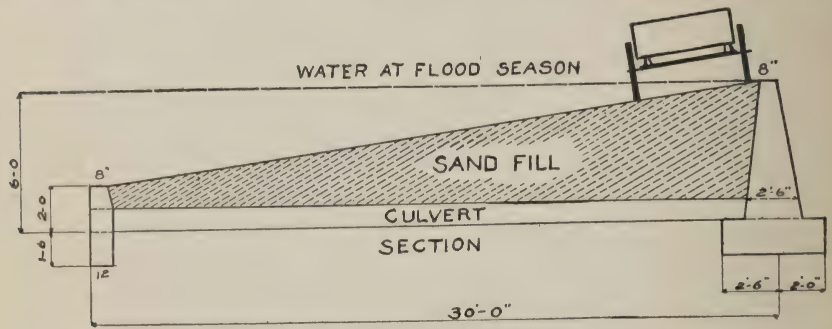

FIG. 4.—Crosscut view showing the method of draining a flooded road with a concrete wall.

crete or cement mortar can be obtained, and in such places a neat permanent wall can be laid.

SWAMP SECTIONS AND LOW LEVELS.

There are roads on which the water stands throughout the whole year and, while they do not become impassable like the flooded areas,

FIG. 5.—Swampy mail route in Georgia.

they are a nuisance to all who are obliged to use them. Pedestrians are sometimes able to cross these sections on plank walks, which, however, are generally neglected. They are impassable for automobiles because of the danger of flooding the engines.

In cases of this description the trouble is caused by the fact that the water can not be drawn away from the road because the road is lower than the level of the adjacent land. It is, therefore, necessary to elevate the road above the water to secure proper drainage.

While a bridge would remedy the trouble in some cases, it must be remembered that this circular is describing those sections which are financially unable to build bridges at present. Moreover, unless the bridge is built of something more permanent than wood, there must be a constant outlay for the maintenance of the bridge floor.

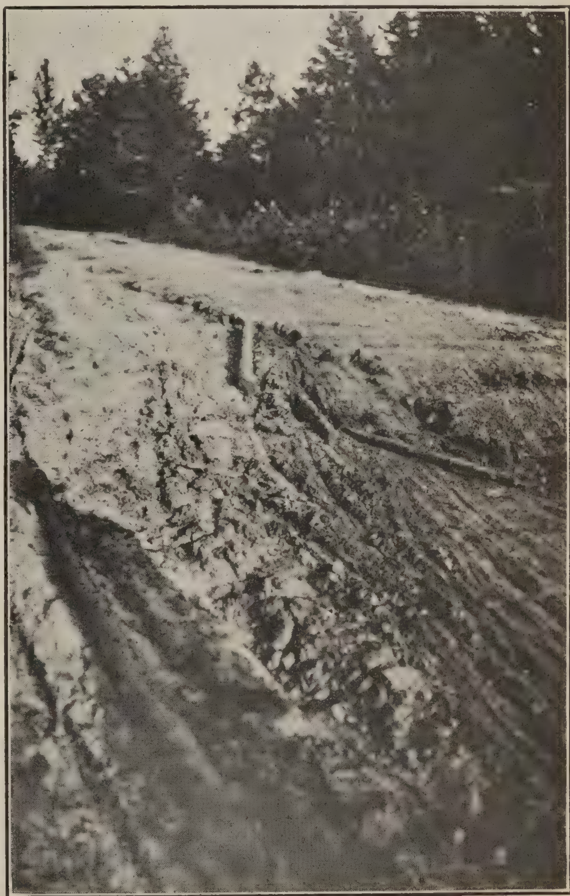

Fig. 6.—Corduroy road near Lunenburg, Va.

On the other hand, to make a fill that would raise the road entirely out of the water would cost a large amount of money, and such a fill would require heavy protection on its slopes, in order that the water might not undermine them. Where a small fill has been made, the local authorities have usually resorted to the corduroy road, which is one of the roughest and most unsatisfactory roads in use. If the material used can absorb moisture to any extent, the fill naturally becomes gradually saturated. As the water must remain on or around the road, it is necessary to use a material that holds as little moisture as possible, and to use it in such a manner as to give a dry road with the least amount of materials.

There is scarcely a section in the South where either rock, clay, or sand can not be obtained. Wherever there is clay, brick will probably be made, and wherever there is a brick kiln, it is possible to secure old brickbats, or at any rate they can generally be found around the sites of old brick buildings.

The method of construction for roads of this description is the same, whether rock, brickbats, or sand are used. The road is first formed in a V-shape by either excavating in the center and throwing the material to the sides or by filling the materials in at the sides of the roadbed to form the sides of the "V." This "V" is next filled with either rock, brickbats, or sand. If it is filled with rock, the largest-sized pieces are kept at the point of the "V," while the smallest are used at the top. For a 15-foot roadbed the rock is placed from 18 to 24 inches thick in the center and to a depth of about 6 inches at a point $7\frac{1}{2}$ feet on each side of the center. The top is then dressed off with natural soil and a road drag is used.

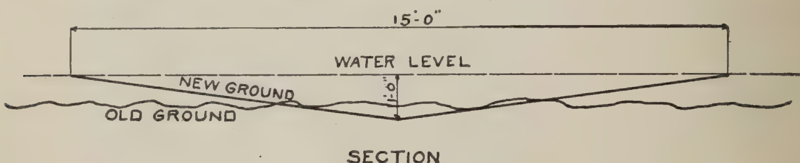

FIG. 7.—Roadbed with V-shaped foundation.

If it is filled with brickbats or sand, the same method is used. The sand section will remain damp and, since sand supports a load better when damp than when dry, this is an advantage.

This type of road is more satisfactory than the old corduroy road, and far less expensive to maintain, because the use of the road drag and an occasional renewal of material when settlement takes place will be the only items of expense. In some sections the "V" has been filled with logs laid parallel with the road, but this method is not recommended except as a temporary measure.

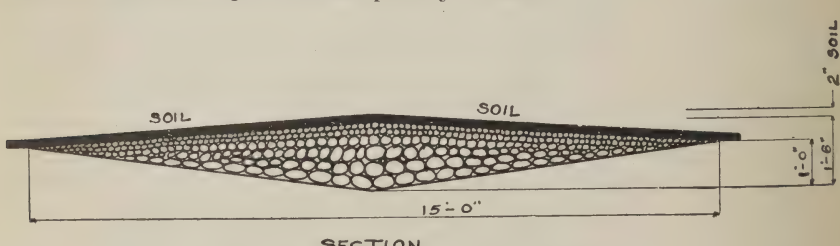

FIG. 8.—V-shaped drain filled with rock, brickbats, or sand.

EROSION OF THE ROAD AND DITCHES.

After hard or prolonged rains, roads which have been constructed with a flat surface are often gullied in the center, or, if the road was well crowned, the gutters or ditches are usually badly washed.

As a rule the damage is more extensive on grades than on level stretches. This is because the damage in general depends upon the velocity of the water, and this of course is controlled by the steepness of the slope. If the water cuts the ditches very deep, it might

be advisable to reduce the grade of the road, if possible, either by cutting down the summit or filling at the foot of the hill, or both. It must be remembered that this is likely to be economical in the end even if the first cost seems high, since it will not only save on future maintenance, but will decrease the tractive force required to

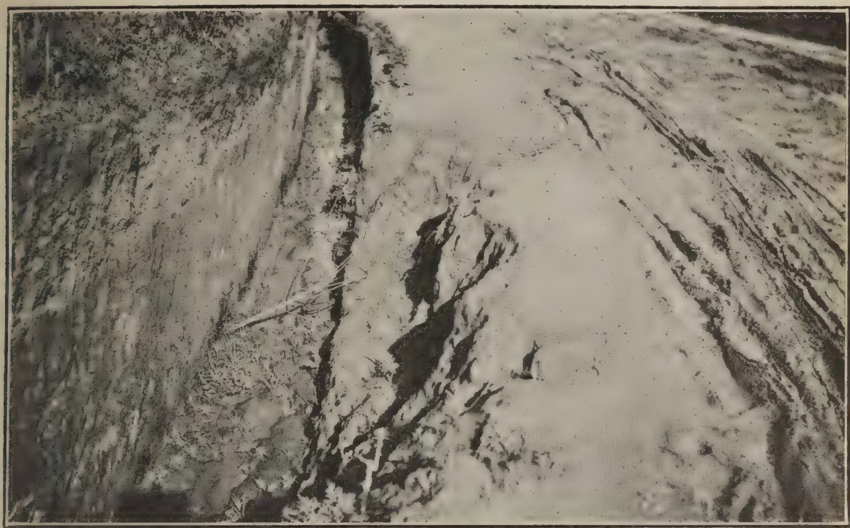

FIG. 9.—Erosion of side ditches on a South Carolina road causing danger to traffic.

pull a load at this point. There are, however, many grades that can not be changed, because of local conditions, and it is the aim of this circular to deal with these cases.

In the case of the sandy sections the wash may be effectively stopped by 2-inch planks from 6 to 12 inches wide and cut into 3-foot sections. These short planks are sharpened on one end and then enough of them to cover 3 feet in width of the gutter or ditch are driven in edge to edge for a depth of over 3 feet at right angles to the grade of the road. If they are driven in a little more than flush with the gutter, there is no danger of the road machine or drag striking them.

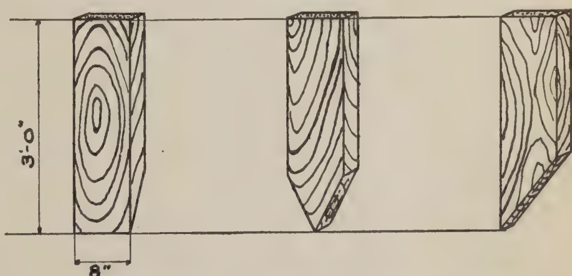

FIG. 10.—Two-inch plank prepared for use in sandy regions.

In a clay section it is practically impossible to drive a plank 3 feet without splintering it. The method of construction is entirely different from that described for sandy sections. Old logs or railroad ties, if they can be secured, are better under these conditions. They

should first be cut into 4-foot lengths. Trenches are then sunk in the gutters at right angles to the road, and the tie or log is placed in the trench. Where the wash is severe, several logs are placed directly over each other like the flashboards in a dam. The top log or tie is placed at least 4 inches below the gutte in order to prevent it from coming in contact with a road drag or road machine in operation.

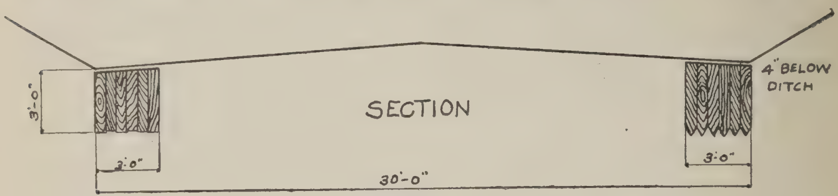

FIG. 11.—Crosscut view of a sandy road protected by planks.

The ties or logs are placed from 20 to 60 feet apart, according to the grade of the hill, and it is an easy matter to insert one whenever an additional one is required.

The chief advantage gained by this use of logs or planks is that deep and dangerous ditches which are not only a menace to travel, but also make the road narrow, are removed. When the planks or

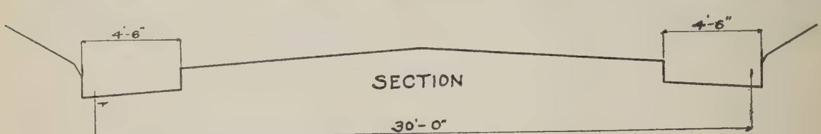

FIG. 12.—Road ditch prepared with trenches to be filled with logs.

logs are used, the entire width of the road can be used by the public, and the road is always safe.

SAND OR CLAY STRETCHES.

Many sand beds that are bad at all seasons can be improved by mixing clay with sand by means of a plow and harrow and then using

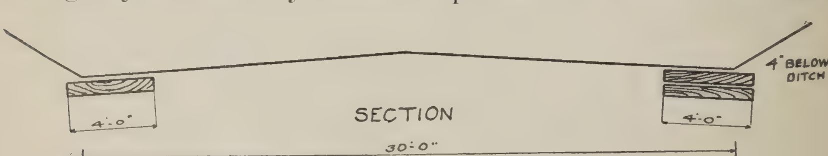

FIG. 13—Road ditch with logs in place.

the road drag systematically. On the other hand, many clay sections that are bad in wet weather can be improved by first plowing and then mixing in sand by means of the harrow, and finally using the road drag.

The Office of Public Roads has issued a publication on the subject of sand-clay roads, and this circular will not therefore enter into the

details of this method of road construction. This publication is Farmers' Bulletin 311, "Sand-clay and Burnt-clay Roads," and copies of it can be obtained upon application to the Secretary of Agriculture, Washington, D. C.

TOP SOIL ROADS.

This type of road has been used with marked success in Virginia and Georgia. While in principle it is a sand-clay type, it is often a sandy soil with just enough loam to fill the voids in the sand and bond the particles together. The road really lies between a sand-clay road and an earth road, and it is well to bear in mind that the best results on earth roads, especially in the South, are obtained when the material is pliable and plastic and can be easily and economically worked. The earth roads are vastly improved if all sod, roots, refuse, and perishable material can be kept out of the roadbed and the surface well crowned.

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Issued November 1, 1911.

U. S. DEPARTMENT OF AGRICULTURE,

OFFICE OF PUBLIC ROADS—CIRCULAR No. 96.

LOGAN WALLER PAGE, DIRECTOR.

NAPHTHALENE IN ROAD TARS.

I.—THE EFFECT OF NAPHTHALENE UPON THE CONSISTENCY OF REFINED TARS.

BY

PRÉVOST HUBBARD,

Chemist, Office of Public Roads,

AND

CLIFTON N. DRAPER,

Assistant Chemist, Office of Public Roads.

WASHINGTON:
GOVERNMENT PRINTING OFFICE.
1911.

LETTER OF TRANSMITTAL.

U. S. Department of Agriculture,
Office of Public Roads,
Washington, D. C., August 2, 1911.

Sir: I have the honor to transmit herewith the manuscript of a circular, by Mr. Prévost Hubbard and Mr. Clifton N. Draper, of this office, on the Effect of Naphthalene upon the Consistency of Refined Tars. This publication is one of a series of papers which will be prepared under the general subject, Naphthalene in Road Tars. A systematic investigation of the effect of various constituents upon the quality and adaptability of tars used as road binders would seem to be of the greatest importance, first, because of the present lack of data bearing upon this subject, and second, because the utilization of tars in road treatment and construction seems destined to effect a large proportion of the road work in this country. I therefore respectfully request that this paper be issued as Circular 96 of this office.

Respectfully,

Logan Waller Page,
Director.

Hon. James Wilson,
Secretary of Agriculture.

THE EFFECT OF NAPHTHALENE UPON THE CONSISTENCY OF REFINED TARS.

Naphthalene, $C_{10}H_8$, often occurs in coal tar in larger quantities than any other one hydrocarbon and for this reason it is natural to suppose that it exerts an appreciable influence upon the quality and applicability of coal tars used as road binders. In this country the use of tars in road treatment and construction has advanced rapidly during the past few years and upon the market to-day are to be found a number of tar preparations intended for such use. These preparations are as a rule made by distilling off the lighter and more volatile constituents from both crude coal tar and crude water-gas tar or mixtures of the two. The residual products, which vary in consistency according to the extent and method of distillation, are sold for road purposes. Many successes and many failures have resulted from the use of coal tar and water-gas tar road binders, and often no clew has been obtainable as to the reason for such diverse results. In view of this fact, a systematic study of the principal chemical constituents of road-tar preparations and their effect upon the quality of such preparations is now being made in the laboratories of the Office of Public Roads, United States Department of Agriculture.

In the present paper, which is the first of a series upon naphthalene, no attempt will be made to review the chemistry of this substance, since this discussion is reserved for a later publication which will cover the entire subject as presented in the individual papers. A few remarks concerning certain physical properties of naphthalene may, however, not be amiss at this point.

Naphthalene, in the pure state, exists in white crystalline masses of thin rhomboidal scales melting at 79° C. and having a boiling point of 218° C. Its specific gravity at 15° C. is 1.1517. It has a very characteristic odor, commonly familiar in moth balls, and is extremely volatile, considering its high molecular weight, so much so that in the manufacture of coal gas it is only partially deposited in the condensers, while the remainder is carried into the purifiers

and into the gas mains, where it deposits in the bends of pipes during cold weather and often causes them to become clogged. Naphthalene volatilizes far below its boiling point and, in crude tars, distills to a considerable extent with aqueous vapor and also with the light tar oils, which accounts for its occurrence in the first fractions. Even at ordinary temperatures, it volatilizes slowly and gives off a penetrating tarry odor. It is slightly soluble in hot water, but dissolves easily in alcohol, ether, fatty and essential oils, acetic acid, and especially in the phenols and lighter tar distillates. No entirely satisfactory method for the quantitative determination of naphthalene in tar has, as far as the authors are aware, been devised up to the present time, although methods have been put forth by various investigators for the determination of naphthalene in illuminating gas.

It is a rather generally accepted theory that, in the manufacture of coal gas, the formation of naphthalene is due to certain complex reactions which take place only at the high temperatures at which the retort is maintained in modern gas-house practice. According to Cooper,[1] "A few years ago—when lower temperatures were in vogue, and when lower makes per ton of coal carbonized were registered—naphthalene was an almost unknown quantity; but now that the stress of competition demands the highest possible output of gas, it seems also to bring in its train the formation of large quantities of naphthalene." It is certain, however, that other factors, such as the size, shape, and inclination of the retort with relation to the volume of the charge of coal, and the varying conditions to which the evolved gases are subjected before and during their passage from the retort, have a great deal to do with the quantity of naphthalene formed.

Tars used as road binders are for the most part soft pitches obtained by distilling from 15 to 30 per cent of the lighter products from the crude material. The soft pitch contains a large proportion of the naphthalene which may have been present in the original tar, and it is the study of the effect of naphthalene upon this grade of material that is the subject of this paper. As consistency is one of the most important properties of a road tar, it was thought well first to investigate the effect of varying percentages of naphthalene upon a given tar.

From its very nature naphthalene itself can not be considered as a binding material. For some time past it has been known, however, to serve as a flux for the binding constituents of tars, in spite of the fact that it is a crystalline solid. Thus it is possible to combine, by heating together, a hard tar pitch and a quantity of naphthalene with the formation of a soft product. It was thought, therefore, that

[1] Journal of Gas Lighting, Vol. CX, May 24, 1910, p. 498.

a comparison of its fluxing value with that of certain less volatile tar distillates would prove most instructive. For this purpose a representative coal tar was taken and distilled to 238° C. in order to remove all the naphthalene. This naphthalene-free tar pitch, which was used for the following tests, was so hard that it was difficult to make an impression on it with the finger. An arbitrary measure of the consistency of this pitch was then obtained by means of the New York Testing Laboratory float-test apparatus, which is customarily used for this purpose in the routine examination of tar products in the Office of Public Roads.[1]

The float apparatus, briefly described, consists of an aluminum float or cup, $3\frac{1}{2}$ inches in diameter, into which is screwed a small brass conical collar or mold. This collar is $\frac{7}{8}$ inch high, with an internal diameter at the top of $\frac{3}{8}$ inch and at the bottom of $\frac{1}{2}$ inch.

In making the test the brass collar is placed with the small end down on a brass plate which has been previously amalgamated with mercury by first rubbing it with a dilute solution of mercuric chlorid nitrate and then with mercury. A small quantity of the material to be tested is heated in a metal spoon until quite fluid, with care that it suffers no appreciable loss by volatilization and that it is kept free from air bubbles. It is then poured into the collar in a thin stream until slightly more than level with the top. The surplus may be removed after the material has cooled to room temperature, by means of a spatula blade which has been slightly heated. The collar and plate are then placed in a tin cup containing ice water maintained at 5° C. and left in this bath for at least 15 minutes. Meanwhile another cup is filled about three-fourths full of water, placed on a tripod, and the water heated to any temperature at which it is desired to make the test. This temperature is accurately maintained, and is at no time throughout the entire test allowed to vary more than one-half a degree centigrade from the temperature selected. After the material to be tested has been kept in the ice water for at least 15 minutes, the collar and contents are removed from the plate and screwed into the aluminum float, which is then immediately floated in the warmed bath. As the plug of bituminous material becomes warm and fluid it is gradually forced upward and out of the collar until water gains entrance to the float and causes it to sink.

The time in seconds between placing the apparatus on the water and when the water breaks through the bitumen is determined by means of a stop watch and is taken as a measure of the consistency of the material under examination. Results so expressed are only relative, but they are comparable to within a good degree of precision. The temperature at which the water bath is maintained is purely an arbitrary matter and, for routine work in the office, 32° C.

[1] Bulletin 38, U. S. Dept. of Agriculture, Office of Public Roads, pp. 14–16.

and 50° C. have been selected as a matter of convenience when testing the comparatively soft and comparatively hard road tars.

For the work described in this circular 55° C. and 80° C. were adopted as most convenient temperatures. The former was selected after making a series of float tests upon the prepared coal tar pitch at temperatures varying from 40° C. to 60° C. In these tests it was found that at 40° C. and 45° C. the tar had not softened sufficiently to complete the test at the end of 1 hour; at 50° C. a test of 24 minutes and 18 seconds was obtained; at 55° C., 9 minutes and 47 seconds, and at 60° C., 3 minutes and 45 seconds. The duration of the test at 55° C. seemed most satisfactory as allowing sufficient leeway for comparative results without consuming too much time. It was decided to select 80° C. as a second working temperature, as it was the nearest convenient one to the melting point of naphthalene. It was thought that, by making consistency tests upon the naphthalene tar-pitch mixtures, later described, at both 55° C. and 80° C., the results would show not only how much the mixtures softened at the higher temperature, but what differences, if any, might be due to naphthalene below and above its melting point.

When the matter of temperatures had been decided upon and the consistency of the tar pitch had been determined at these temperatures, naphthalene mixtures were made as follows: Approximately 30-gram samples were accurately weighed into a series of small tin dishes, and varying percentages of c. p. flake naphthalene were added, starting with 0.5 per cent of naphthalene and gradually increasing this amount to the extent of 30 per cent. In all, 13 samples were prepared. Before adding the naphthalene, each weighed sample of tar was warmed in the tin dish until fairly fluid, after which the naphthalene was added and the mixture well stirred. It was found better to add the naphthalene a little at a time during the process of mixing rather than to add the entire amount at one time, as by so doing there was less danger of losing some of the naphthalene by volatilization and a uniform mixture was more readily obtained. As the naphthalene was added, an increase in the fluidity of the mixtures was readily seen. Where 20 per cent of naphthalene was used, the mixture was found to be fluid at normal temperatures, whereas the original pitch was semisolid. The naphthalene combined with the tar with surprising readiness and, upon cooling, no traces of the naphthalene could be seen in the resulting mixture, except where high percentages were added. It was found, however, that between 15 and 20 per cent of naphthalene caused the tar to become saturated. The 15 per cent mixture was homogeneous when cold, but in the 20 per cent mixture a small amount of naphthalene crystals separated out upon cooling. This fact indicates that the tar pitch forms a sort of eutectic with naphthalene similar to certain metallic alloys. Above the approximate eutectic of 20 per cent the

naphthalene crystallized out more and more as the percentage was increased. A mixture of 30 per cent of naphthalene solidified. This was due to the crystallization of the excess of naphthalene. The consistency of this mixture at 55° C. was found to be higher than the preceding mixtures, owing to the separation of the naphthalene, which does not melt at this temperature. At 80° C. the consistency

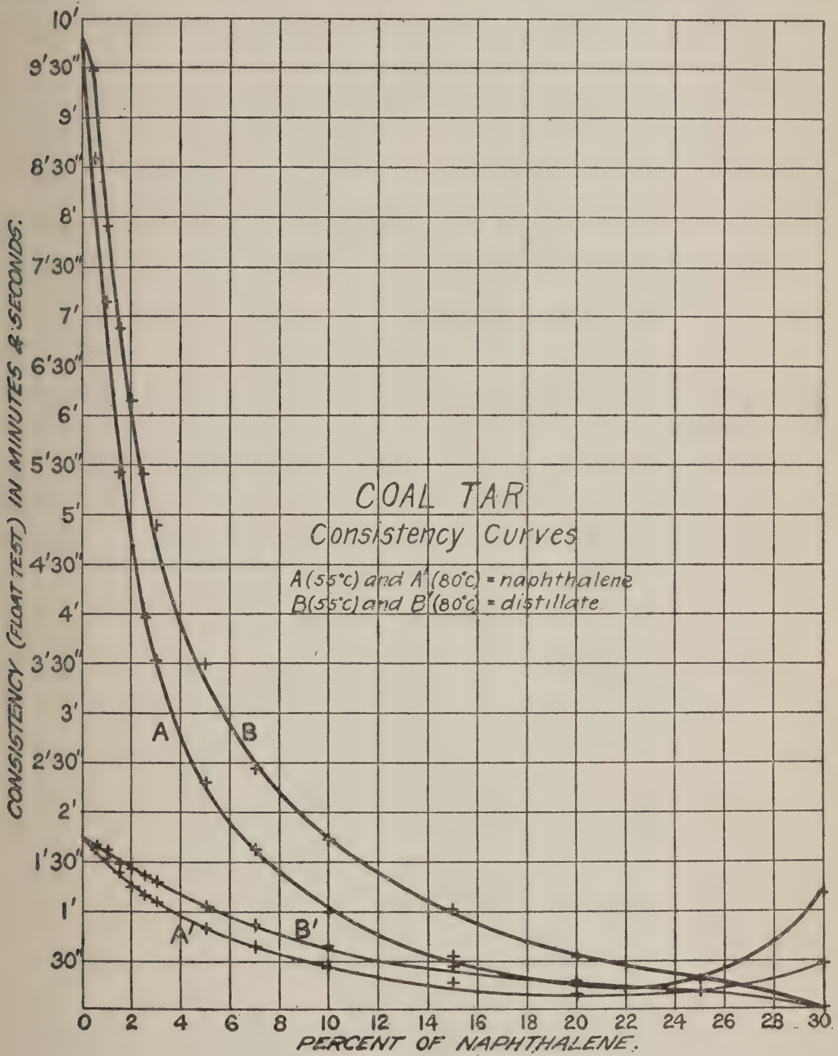

FIG. 1.

of this mixture was nil; that is, it became very fluid, as would naturally be expected. The maximum increase of fluidity of the tar was obtained with 20 per cent of naphthalene, which is practically the eutectic point. These facts will be noticed on the curves A and A′ (fig. 1), which show the consistency of the mixtures plotted against the varying percentages of naphthalene.

Curve A shows the decided effect which naphthalene has upon the tar at 55° C., and A′ the effect at 80° C. As the temperature of the water bath during the float test is raised, the curve A will approach A′ and a series of curves might be obtained, lying between A and A′, for water-bath temperatures between 55° C. and 80° C.

The sensitiveness of the tar pitch to small increments of naphthalene is shown by the sharp drop in the first section of curve A, starting with the addition of 0.5 per cent of naphthalene, which increases the fluidity 1 minute 12 seconds. The fluidity increases very markedly until 7 per cent of naphthalene is reached, when the curve becomes more gradual, while increasing percentages of naphthalene have a much smaller effect. The curve drops, however, until 20 per cent of naphthalene is reached and then rises gradually to 25 per cent of naphthalene, owing to the separation of naphthalene, as previously explained. At 30 per cent of naphthalene a sharp rise is noted and the curve, if continued further, would rise almost perpendicularly, because the naphthalene is so much in excess that an accurate measurement of the consistency would be impossible. For reference to the percentage increase in fluidity owing to increasing increments of naphthalene, the data given in Table I calculated from the curves will show statistically what the curves represent graphically.

TABLE I.—*Percentage increase in fluidity of coal-tar pitch owing to additions of naphthalene and naphthalene-free tar distillate.*

Per cent of naphthalene or distillate.	Due to naphthalene.		Due to distillate.	
	At 55° C.	At 80° C.	At 55° C.	At 80° C.
	Per cent.	*Per cent.*	*Per cent.*	*Per cent.*
0.5	12.2	6.7	3.1	3.8
1.0	26.9	11.5	19.1	5.8
1.5	44.5	19.2	29.6	14.4
2.0	50.8	27.9	37.1	17.3
2.5	59.3	32.7	44.6	20.2
3.0	64.1	36.5	49.9	25.0
5.0	76.5	51.0	64.2	39.4
7.0	83.3	63.5	75.1	49.0
10.0	91.5	75.0	82.3	61.5
15.0	94.4	83.7	89.6	74.0
20.0	97.3	90.4	94.5	83.7
25.0	96.9	89.4	96.6	89.4
30.0	88.1	75.0	100.0	100.0

It will be observed that 7 per cent of naphthalene increases the fluidity of the tar 83.3 per cent at 55° C., while 20 per cent increases it 97.3 per cent, showing that the additional 13 per cent of naphthalene makes an increase of only 14 per cent in fluidity. This fact is shown by the gradual slope of the curve A between these points as contrasted with the steep slope up to 7 per cent.

For comparison with the consistency results obtained with naphthalene, a portion of the original coal-tar pitch was saved for

use in mixtures with a naphthalene-free tar distillate. Duplicate tests were carried out in the same way as were the naphthalene tests, except that equivalent percentages of a naphthalene-free distillate were employed. This distillate was a mixture of oils taken from the distillation of several water-gas tars and showed the following composition upon fractional distillation in an Engler flask:

TABLE II.—*Fractional distillation of tar distillate.*

Temperature in ° C.	Per cent distilled.	Temperature in ° C.	Per cent distilled.
Up to 190	0.7	Up to 280	47.5
Up to 200	1.0	Up to 290	55.5
Up to 210	1.8	Up to 300	62.5
Up to 220	5.0	Up to 310	71.0
Up to 230	7.5	Up to 320	77.5
Up to 240	14.5	Up to 330	83.0
Up to 250	23.0	Up to 340	89.0
Up to 260	28.5	Up to 346 [1]	94.0
Up to 270	37.0		

[1] Dry.

The specific gravity of this distillate was 1.006 at 25° C. and, upon cooling to −10° C., no solids crystallized out of solution.

Thirteen samples were weighed out in the same manner as for the naphthalene tests and the percentages of distillate added as before. Consistency results were obtained upon the mixtures of tar and distillate, according to the float apparatus, and at the same temperatures as in the naphthalene tests—55° C. and 80° C. The procedure was exactly duplicated in both cases, so that the results could be studied under exactly the same conditions. In figure 1 the results of this second series of tests are shown by curves B and B′, and the corresponding tabulated data are shown in Table I as compared with the results from naphthalene.

The effect exerted by naphthalene upon the fluidity of tar is, from these results, a very important one in coal tars used for road construction. All coal tars contain naphthalene, but the amount in road-tar preparations varies from 0 to 10 per cent and higher. The degree of fluidity which a tar maintains under service conditions is a most important consideration. The fact that a tar is originally of proper consistency for certain work is no reason for supposing that this consistency will be maintained under service conditions. If the fluidity of the tar is due principally to nonvolatile tar oils, it will undoubtedly maintain its original consistency for a longer period than if the fluidity is due mainly to high naphthalene content. Therefore, in two tars of the same consistency or degree of fluidity, one with a small naphthalene content and the other with a high naphthalene content, it would be natural to predict from the foregoing data that upon exposure the low naphthalene tar would main-

tain its original consistency for a longer time, if other things are equal. Owing to the volatility of naphthalene, the high naphthalene tar would undoubtedly lose more or less naphthalene, and hence its fluidity might be expected to decrease rapidly. This subject is now under investigation and will be covered in a later paper.

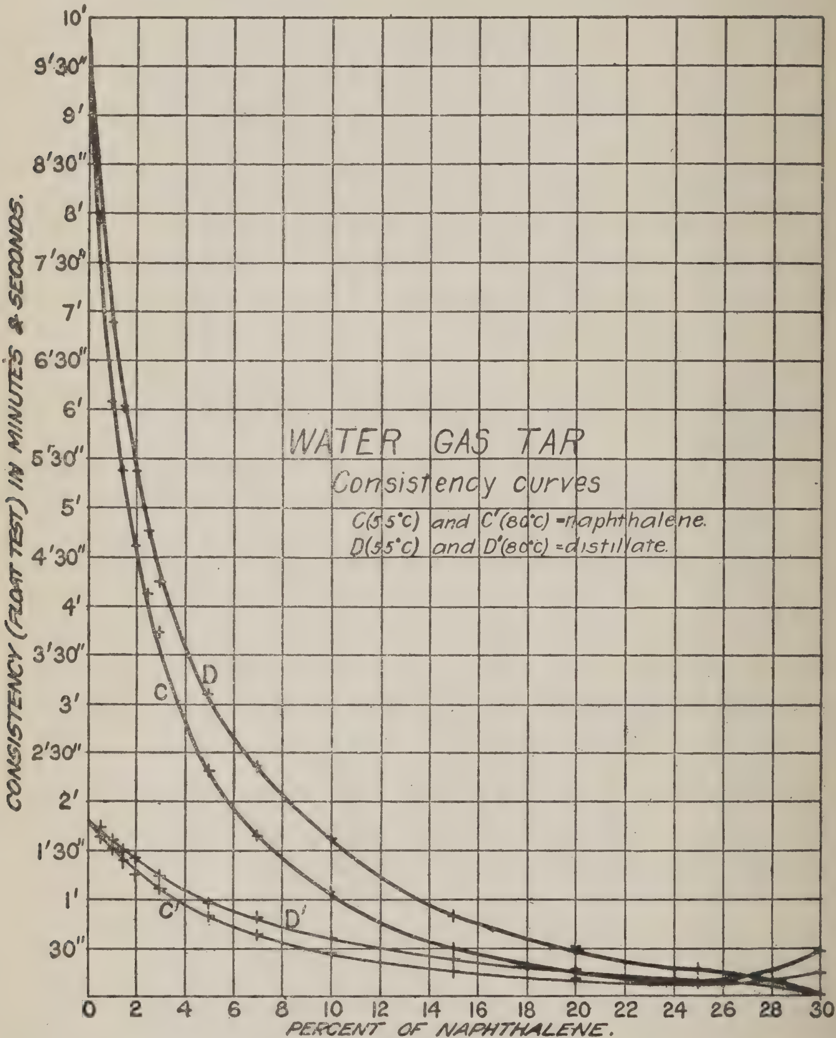

FIG. 2.

In addition to refined coal tars, refined water-gas tars and also refined mixtures of coal tar and water-gas tar are used to a considerable extent in the treatment and construction of roads. For this reason it was thought advisable to determine what effect naphthalene might have upon the consistency of a water-gas tar pitch. Water-gas tar as produced in the modern manufacture of carburetted water

gas is similar in many ways to its sister product, coal tar. It has, however, marked characteristics in which it differs from coal tar, namely, a lower specific gravity, a lower free-carbon content, and a relatively small amount of naphthalene.

A representative sample of water-gas tar was distilled until the residual pitch had as nearly as possible the same consistency at 55° C. as the coal-tar pitch in the previous experiments. This water-tar pitch had a consistency of 9 minutes 49 seconds. It was divided into two portions, one for naphthalene mixtures and one for distillate mixtures. As in the previous work, samples were weighed out with varying percentages of naphthalene and a duplicate set of samples with an equivalent amount of the same naphthalene-free tar distillate as used in the coal-tar tests. The consistency was obtained in both sets of tests with the float apparatus, and the water bath was maintained at 55° C. and 80° C., respectively. The results from the naphthalene series are shown in figure 2 by curves C and C′, and those of the corresponding distillate series by curves D and D′.

It will be noted that these curves follow very closely those shown in figure 1 and are of the same general type. The relation between the consistencies obtained with naphthalene and the naphthalene-free distillate is practically the same as for coal tar, and the respective influence of the increase in fluidity is similar, as shown in Table III. Indeed, this similarity is remarkably close when it is realized that the coal-tar pitch contained 18.34 per cent of free carbon, while the water-gas tar pitch contained only 1.77 per cent of free carbon.

TABLE III.—*Percentage of increase in fluidity of water-gas tar pitch, owing to additions of naphthalene and naphthalene-free tar distillate.*

Per cent of naphthalene or distillate.	Due to naphthalene.		Due to distillate.	
	At 55° C.	At 80° C.	At 55° C.	At 80° C.
	Per cent.	*Per cent.*	*Per cent.*	*Per cent.*
0.5	21.1	5.5	18.8	4.6
1.0	38.0	15.6	29.7	11.9
1.5	45.2	22.0	38.5	16.5
2.0	53.0	30.3	45.2	21.1
2.5	57.9	33.0	51.4	26.6
3.0	62.0	38.5	56.7	31.2
5.0	76.4	54.1	68.4	46.8
7.0	83.1	64.2	75.9	55.0
10.0	89.0	75.2	83.5	67.0
15.0	94.9	86.2	91.5	78.9
20.0	97.1	89.9	94.7	86.2
25.0	98.5	92.7	97.1	90.8
30.0	95.2	87.2	100.0	100.0

Comparing these data with those tabulated for the coal-tar tests, it will be noted that the effect of small percentages of naphthalene is even greater for the water-gas tar than for the coal tar of like consistency, and this is also true of the naphthalene-free distillate, although

the effect is not so marked. The principal difference between the two sets of curves at 55° C. is the marked increase in fluidity caused by both naphthalene and distillate when only 0.5 per cent is added, as even as small an addition as this increases the fluidity by 21.1 and 18.8 per cent, respectively. This fact is shown by the sharp drop in both water-gas tar curves at 55° C. The two series of curves obtained at 80° C. are also similar. The effect of increasing amounts of naphthalene, however, is not so markedly shown as in the curves for the test at 55° C.

In a paper by one of the authors,[1] on the effect of free carbon in tars from the standpoint of road treatment it is shown that an increase in the percentage of free carbon to tar bitumen of a given consistency decreases the fluidity of the resulting product. It is evident, therefore, that the true bitumen of the two tar pitches under investigation, excluding free carbon, differed somewhat, although the pitches as prepared were of the same consistency.

While at the present time it does not seem advisable to draw very definite conclusions, the foregoing results nevertheless strongly indicate the following facts:

(1) That the fluxing value of naphthalene for tar pitches is somewhat greater, although quite similar, to the heavier naphthalene-free tar distillates, until the mixture becomes saturated with naphthalene;

(2) That for the harder tar pitches the addition of very small percentages of naphthalene will produce a marked increase in fluidity of the resulting product;

(3) That for the softer pitches the addition of naphthalene in small quantities causes less increase in fluidity than for the harder pitches;

(4) That where naphthalene is added beyond the point of saturation a rapid decrease in the fluidity of tars at temperatures below the melting point of naphthalene is observed, but at temperatures above its melting point the fluidity continues to increase.

In conclusion, it may be stated that evidence points to the fact that, within a reasonable degree of accuracy, it should be possible to foretell, by reference to the curves which have been given, what consistency to expect from the addition of a given percentage of naphthalene to a tar pitch or refined tar of known consistency, irrespective of the free carbon content of the tar.

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[1] Proc. Am. Soc. Test. Mat., 1909, Vol. IX, p. 549.

Issued February 7, 1912.

U. S. DEPARTMENT OF AGRICULTURE,
OFFICE OF PUBLIC ROADS—Circular No. 97.
LOGAN WALLER PAGE, Director.

COKE-OVEN TARS OF THE UNITED STATES.

BY

PRÉVOST HUBBARD,
Chemist, Office of Public Roads.

WASHINGTON:
GOVERNMENT PRINTING OFFICE.
1912.

LETTER OF TRANSMITTAL.

United States Department of Agriculture,
Office of Public Roads,
Washington, D. C., October 19, 1911.

Sir: I have the honor to transmit herewith the manuscript of a circular by Mr. Prévost Hubbard, chemist in this office, entitled "Coke-Oven Tars of the United States." This publication gives the results of examinations of all the coke-oven tars at present manufactured in this country, together with a brief discussion of their properties in relation to their use as road materials. I respectfully request that this manuscript be published as Circular 97 of this office.

Respectfully,

Logan Waller Page,
Director.

Hon. James Wilson,
Secretary of Agriculture.

COKE-OVEN TARS OF THE UNITED STATES.

The rapidly increasing use in this country of refined coal tar in the treatment and construction of roads and the fact that an immense quantity of coal tar will ultimately become available for this purpose through the installation of by-product coke ovens make it highly desirable to obtain accurate information as to the properties of coke-oven tars which are being produced at present. Attention was called by the author to the importance of this subject in a recent publication,[1] as follows:

While, in the manufacture of coal gas, the production of tar is absolutely unavoidable, this is not true of the manufacture of coke for metallurgical purposes. There are two general types of coke ovens in use at present, in one of which no attempt is made to recover the volatile products of the coal. This is the oldest form of oven, known as the "beehive," and is extensively used in this country to-day. It is constructed of brick and as its name implies has the form of a beehive. Bituminous coal is placed in this oven or kiln and a part of it burned in order to carbonize the remainder, while the volatile products, such as gas, ammonia, and tar, are allowed to escape through an opening in the top of the kiln, where they are lost in flame and smoke.

Coke ovens in which the by-products are saved are now used to some extent in this country, and sooner or later will undoubtedly replace the old-style oven entirely, and thus increase our output of tar enormously. The reason that they have not been more generally adopted in this country is that in the United States tars are of much less economic importance than in the European countries, where great chemical industries are based upon the utilization of this material. Germany in particular is far in advance of us in this field and exports to this country alone coal-tar products to the value of several million dollars each year. With the development of the road-tar industry, which promises to consume vast quantities of tar, and the necessity for refining such tars before use, the general adoption of by-product ovens is only a matter of time. What this will mean in the increase in tar production can be imagined from the fact that in 1908, out of a total of over 26,000,000 tons of coke produced in coke ovens, only a little over 4,000,000 tons were obtained from by-product

[1] Dust Preventives and Road Binders, pp. 239–240, New York.

ovens. About 22,000,000 tons of coke were, therefore, produced without recovery of the tar. As the average yield of coke per ton of coal was 66 per cent, this would represent the consumption of over 33,000,000 tons of coal. Upon the basis of a yield of 10 gallons of tar per ton of coal, it may be seen that over 330,000,000 gallons of tar were lost in 1908 which might have been saved. As the actual production of coal tar both from coke ovens and gas houses amounted to about 101,000,000 gallons, it is evident that over three-fourths of our possible production of tar as a by-product was lost during that year. At a valuation of 2½ cents per gallon, this means a loss of over $8,000,000. With such an increase in production, however, the monetary value of coal tar would have dropped, so that this figure may be somewhat exaggerated. In any event, at a conservative estimate, the tar lost each year from nonrecovery coke ovens is sufficient to build 9,000 miles of tar macadam road 15 feet wide.

This estimate was based on data taken from reports of the United States Geological Survey. In a later report by Parker,[1] it is shown that over 53,000,000 tons of coal were consumed in beehive ovens in 1910, so that on the same basis it would appear that over 530,000,000 gallons of tar were lost during that year. The output of tar from by-product coke ovens, however, has also continued to increase, as shown by the following figures taken from this report:

Tar obtained from by-product coke ovens.

	Gallons.
1908	42, 720, 609
1909	60, 126, 006
1910	66, 303, 214

The tar thus produced in 1910 was valued at $1,599,453, or about 2.4 cents per gallon. It is evident, therefore, that the value of the tar lost during that year by the use of beehive ovens amounted to approximately $12,000,000. That the use of by-product ovens is increasing in greater proportion than the use of the beehive oven is shown by the fact that for the former type the increase in 1910 over 1909 in tons of coke produced was 14.13 per cent, while the production from beehive ovens increased by only 4.57 per cent. Parker adds, however:

> While noteworthy progress has been made in the substitution of modern retort-oven practice for the wasteful and what should be obsolete beehive or partial-combustion method of coke making in the United States, this country is still much behind European countries in this regard.

He says further:

> The yield of coal in coke in retort ovens exceeds that obtained in beehive or other partial-combustion ovens by about 15 per cent, and generally the quality of the coke is improved.

[1] The Manufacture of Coke in 1910, United States Geological Survey.

In order to determine the character of coke-oven tars at present being produced in the United States, it was first necessary to obtain samples from all of the known plants, and for this purpose reference was made to a list of by-product and retort coke-oven plants of the United States and Canada (Jan. 1, 1910), which was kindly loaned to the author by Mr. Parker in advance of its publication.[1] Letters were then written to each plant asking for the following information:

(1) *a.* At what maximum temperature are your retorts fired in your ——— ovens? In your ——— ovens?

b. What is the maximum temperature to which the charge of coal is brought in your ——— ovens? In your ——— ovens?

(2) What is the specific gravity of your crude tar in your ——— ovens? In your ——— ovens?

(3) What percentage of free carbon is found in your crude tar from your ——— ovens? From your ——— ovens?

(4) Will you furnish us for examination a 1-gallon sample of your crude tar from your ——— ovens? From your ——— ovens? To be sent at our expense.

Very courteous replies were received from the manufacturers, and in practically every case samples of tar were also forwarded. The blanks in these questions were filled out by inserting the names of the type or types of ovens operated by the manufacturer to whom they were sent. It was found that, where two types of ovens were operated at the same plant, no attempt was made to separate the tar, and the entire output was run into a common well. In such cases the sample of tar submitted was a mixture obtained from both ovens. The report of these samples is given at the bottom of Table I.

The questions concerning temperature were asked because criticism from an authoritative source had been received with regard to a statement made by the author in a former publication[2] to the effect that in the production of tar from by-product coke ovens "*carbonization is conducted at a lower temperature than in the manufacture of coal gas.* The resulting tar, therefore, contains a smaller amount of free carbon, averaging from 3 to 10 per cent * * *." But little reliable information on this subject could be obtained from published literature, although the opinion seemed to prevail that carbonization in by-product coke ovens is conducted at a lower temperature than in modern gas-house practice. Thus, according to Lunge,[3] "Hilgenstock (J. Gasbeleucht., 1902, 617) attributes the notorious difference between gas-tar and coke-oven tar with respect of their contents of free carbon and other products of pyrogenetic decomposition to the fact that in coke ovens the escaping vapors do not attain temperatures above 600° C., and that they are, moreover, protected against decomposition by the dilution of the heavy vapors, slowly given off from the

[1] Mineral Resources of the United States, 1909, Part II, pp. 240–242, United States Geological Survey.

[2] Circular 93, Office of Public Roads, U. S. Department of Agriculture, p. 9.

[3] Coal Tar and Ammonia, 4th ed., part 1, p. 23, Van Nostrand.

TABLE I.—*Analyses of crude coke-oven tars*

	General information.		Answers to questions.			
Serial No.	Company and location.	Type of oven.	Maximum temperature of firing retorts.	Maximum temperature to which coal is brought.	Specific gravity of crude tar.	Per cent of free carbon in tar.
5126	Solvay Process Co., Syracuse, N. Y.	Semet-Solvay.	1050–1450° C.	950–1150° C.	1.12–1.21	3–12
5123	Semet-Solvay Co., Pennsylvania Steel Co., Steelton, Pa.	do.	1050–1450° C.	950–1150° C.	1.12–1.21	3–12
5124	Semet-Solvay Co., National Tube Co., Benwood, W. Va.	do.	1050–1450° C.	950–1150° C.	1.12–1.21	3–12
5137	Semet-Solvay Co., Milwaukee Coke & Gas Co., Milwaukee, Wis.	do.	1050–1450° C.	950–1150° C.	1.12–1.21	3–12
5121	Semet-Solvay Co., Pennsylvania Steel Co., Lebanon, Pa.	do.	1050–1450° C.	950–1150° C.	1.12–1.21	3–12
5125	By-Products Coke Corporation, South Chicago, Ill.	do.	1050–1450° C.	950–1150° C.	1.12–1.21	3–12
5128	Semet-Solvay Co., Detroit, Mich.	do.	1050–1450° C.	950–1150° C.	1.12–1.21	3–12
5200	Semet-Solvey Co., Empire Coke Co., Geneva, N. Y.	do.	1050–1450° C.	950–1150° C.	1.12–1.21	3–12
5189	Semet-Solvay Co., Dunbar Furnace Co., Dunbar, Pa.	do.	1050–1450° C.	950–1150 C°.	1.12–1.21	3–12
5160	Semet-Solvay Co., Central Iron & Coal Co., Tuscaloosa, Ala.	do.	1250° C.	1150° C.	1.17	5.72
5074	Philadelphia Suburban Gas & Electric Co., Chester, Pa.	do.	1050° C.	1000° C.	1.16 (20° C.)	...
5081	Semet-Solvay Co., Ensley, Ala.	do.	1250° C.	1150° C.	1.17 (15° C.)	8
5095	The New England Gas & Coke Co., Everett, Mass.	Otto Hoffman.	[1] 1100° C.	[1] 1200° C.	1.17	8–10
5083	Lackawanna Steel Co., Lackawanna Iron & Steel Co., Lebanon, Pa.	do.	1000° C. (1800° F.)	1000° C. (1800° F.)	1.10	16–24
5159	Dominion Tar & Chemical Co., Sydney, Nova Scotia.	do.	(2)	(2)	1.170	10–15
5107	Hamilton Otto Coke Co., Hamilton, Ohio.	do.	1111° C. (2000° F.)	1111° C. (2000° F.)	1.14	[6] 16.0
5086	Carnegie Steel Co., South Sharon, Pa.	United Otto.	1666° C. (3000° F.)	1444° C. (2600° F.)	1.2	7.09–10.64
5078	Maryland Steel Co., Sparrows Point, Md.	do.	1333° C. (2400° F.)	1222° C. (2200° F.)	[3] 1.19	[3] 8–10
5087	Citizens' Gas Co., Indianapolis, Ind.	do.	1222° C. (2200° F.)	1222° C. (2200° F.)	1.14–1.15	4–5
5109	Pittsburg Gas & Coke Co., The United Coke & Gas Co., Glassport, Pa.	do.	(2)	(2)	(50° F.) 1.207 10° C.	16.59
5122	Zenith Furnace Co., Duluth, Minn.	do.	1222–1277° C. 2200 - 2300° (F.)	(2)	(2)	(2)
5188	Illinois Steel Co., Joliet, Ill.	Koppers.	1444° C. (2600° F.)	1388° C. (2500° F.)	1.16–1.20	12–15
5404	Illinois Steel Co., Indiana Steel Co., Gary, Ind.	do.	1100° C.	880 - 950° C.	[4] 1.174 1.169	4.35
5108	Camden Coke Co., Camden, N. J.	Otto Hoffman. United Otto.	1000° C. (1800° F.) 1222° C. (2200° F.)	833° C. (1500° F.) 1055° C. (1900° F.)	1.20–1.30 [5] (1.221)	7–9 [5] (7.3)
5127	Cambria Steel Co., Johnstown, Pa.	Otto Hoffman. United Otto.	1111° C. (2000° F.) 1111° C. (2000° F.)	[1] 1111° C. (2000° F.) [1] 1111° C. (2000° F.)	1.12	[1] 15
5089	Lackawanna Steel Co., Buffalo, N. Y.	United Otto. Rothberg.	1000° C. (1800° F.) 1000° C. (1800° F.)	1000° C. (1800° F.) 1000° C. (1800° F.)	1.16	16–24

[1] Approximately.
[2] No information.
[3] Varies with coal. Coal with 28 per cent of volatile matter used.
[4] With H_2O.
[5] At present.
[6] Variable.
[7] Trace.
[8] Trace of solids.
[9] Distillate, solid.
[10] Distillate, one-fourth solid.
[11] Distillate, nine-tenths solid.
[12] Distillate, three-fourths solid.
[13] Distillate, eight-ninths solid.
[14] Distillate, one-half solid.

produced in the United States and Canada.

Examination, Office of Public Roads.																		
Specific gravity of tar, 25° C.	Per cent of free carbon.	Per cent of ash.	Per cent soluble in CS_2, including H_2O.	Distillation results.														Serial No.
				Water.		Light oils up to 110° C.		Middle oils, 110°–170° C.		Heavy oils, 170°–270° C.		Heavy oils, 270°–315° C.		Pitch.				
				Per cent by volume.	Per cent by weight.	Per cent by volume.	Per cent by weight.	Per cent by volume.	Per cent by weight.	Per cent by volume.	Per cent by weight.	Per cent by volume.	Per cent by weight.	Per cent by volume.	Per cent by weight.			
1.195	7.76	0.12	92.12	1.0	0.8	[8] 0.3	0.3	0.8	0.7	[12] 13.1	11.5	[19] 8.2	7.3	[25] 76.6	79.1	5126		
1.206	8.77	.07	91.16	1.0	.8	.4	.3	[9] 2.0	1.7	[9] 14.0	12.3	[20] 7.9	6.9	[26] 74.7	77.6	5123		
1.176	7.14	.04	92.82	1.1	1.0	1.9	1.5	.7	.6	14.9	13.2	[21] 11.9	10.6	[27] 69.5	73.1	5124		
1.168	6.10	.05	93.85	1.8	1.5	1.4	1.2	.8	.6	[13] 21.1	18.9	[20] 5.5	4.9	[25] 69.4	72.5	5137		
1.173	4.71	.06	95.23	.6	.5	1.6	1.3	.8	.6	[14] 17.5	15.5	[19] 9.4	8.4	[25] 70.1	73.7	5121		
1.191	7.49	.03	92.48	(7)	(7)	.4	.3	[12] 1.1	.9	[15] 23.6	20.7	[9] 9.8	8.9	[27] 65.1	68.9	5125		
1.169	6.56	.11	93.33	6.9	5.9	[9] 2.8	2.3	[9] .4	.3	[11] 14.6	13.0	[8] 6.9	5.7	[26] 68.4	72.0	5128		
1.159	6.07	.08	93.85	4.0	3.4	2.6	2.1	.6	.5	[10] 17.6	15.5	[22] 11.4	10.4	[27] 63.8	67.7	5200		
1.181	8.85	.02	91.13	2.0	1.7	1.7	1.4	.2	.2	[16] 20.0	17.8	[21] 6.5	5.7	[25] 69.6	73.1	5189		
1.159	5.05	.02	94.93	3.2	2.8	2.4	1.9	.3	.3	18.6	16.3	[10] 7.5	6.8	[27] 68.0	71.5	5160		
1.141	3.96	.05	95.99	2.3	2.0	2.3	1.3	1.2	.8	22.8	19.5	[19] 13.6	12.5	57.8	62.6	5074		
1.175	6.90	.06	93.04	3.3	2.8	[8] 1.4	1.0	.2	.2	[17] 16.5	14.1	[14] 9.3	8.2	[27] 69.3	73.2	5081		
1.160	13.94	.00	86.06	2.2	2.0	2.9	2.3	.6	.5	23.5	20.4	[17] 15.6	14.4	[27] 55.2	59.7	5095		
1.214	14.05	.13	85.82	5.4	4.4	[9] 1.4	1.4	[9] .1	.1	[11] 13.0	10.9	[21] 9.4	8.1	[25] 70.7	74.6	5083		
1.143	10.81	.05	89.14	3.2	2.8	1.9	1.5	.6	.5	27.2	24.2	[19] 7.3	6.7	[27] 59.8	63.5	5159		
1.160	8.37	.06	91.57	3.4	3.0	3.1	2.5	.7	.6	27.9	24.4	[19] 3.8	3.5	[27] 61.1	64.9	5107		
1.191	7.89	.03	92.08	1.0	1.0	[9] 1.6	1.2	[9] .6	.4	[16] 12.1	10.2	[19] 11.0	9.7	[25] 73.7	77.5	5086		
1.179	8.49	.03	91.48	1.6	1.3	1.3	.9	.6	.4	[12] 17.2	15.1	[21] 9.6	8.5	[28] 69.7	73.2	5078		
1.133	5.21	.07	94.72	1.2	1.1	1.1	.9	1.4	1.3	23.9	21.4	[10] 11.6	10.4	[27] 60.8	64.7	5087		
1.176	10.53	.04	89.43	1.1	1.0	1.1	.9	.5	.4	[18] 26.9	23.6	[14] 6.9	6.3	[27] 63.5	67.6	5109		
1.195	12.18	.05	87.77	3.6	3.0	1.7	1.3	.4	.3	[11] 18.1	15.9	[19] 12.5	11.1	[27] 63.7	67.8	5122		
1.171	3.89	.06	96.05	1.9	1.6	[9] 1.7	1.2	[9] .2	.2	[9] 20.0	18.0	[11] 13.4	12.0	[26] 62.8	66.3	5188		
1.169	2.73	.04	97.23	3.5	3.0	[9] 1.3	1.0	[9] .4	.3	[9] 20.6	18.5	[9] 7.1	6.5	[26] 67.1	70.2	5404		
} 1.182	11.30	.06	88.64	2.2	1.9	1.8	1.4	.6	.5	[14] 20.5	18.2	[23] 8.5	7.5	[25] 66.4	70.1	5108		
1.211	12.40	.16	87.44	10.1	8.3	[9] 3.1	2.3	[9] .3	.2	[9] 7.1	6.1	[12] 7.4	6.9	[26] 72.0	74.8	5127		
1.210	16.80	.00	83.20	2.7	2.2	[10] .5	.3	[9] 2.2	1.7	[9] 11.7	9.9	[24] 11.8	10.2	[27] 71.1	75.0	5089		

[15] Distillate, two-thirds solid.
[16] Distillate, four-fifths solid.
[17] Distillate, seven-eighths solid.
[18] Distillate, one-ninth solid.
[19] Distillate, one-third solid.
[20] Distillate, one-sixth solid.
[21] Distillate, one-fifth solid.
[22] Distillate, two-fifths solid.
[23] Distillate, one-seventh solid.
[24] Distillate, three-fifths solid.
[25] Pitch, soft and sticky.
[26] Pitch, very soft and sticky.
[27] Pitch, hard and brittle.
[28] Pitch, plastic.

interior of the coal block, with the fire-resisting gases escaping at the same time from the outer zone of the block. On the other hand, in the case of gas retorts, the heavy vapors escape at once undiluted by the fire-resisting gases which are set free afterwards, and the heavy gases are thus exposed to the white heat of the upper part of the retort."

Answers given by the manufacturers with respect to this question indicate only an approximate knowledge. In general it may be said that carbonization below 970° C. is considered low temperature; from 970° C. to 1,100° C., medium temperature; and from 1,100° C. to 1,540° C. high temperature; and that modern gas-house practice involves the use of high temperatures. However this may be, it is not the purpose of this circular to compare coke-oven tars with gas-house tars, but to consider the former with relation to their utility as road materials.

From a total of 31 manufacturers to whom the questions were submitted 30 replies were received, but 4 of these reported their plants as not in operation. The remaining 26 furnished samples of their crude tar for examination and answered the questions in so far as they were able. Upon receipt of each sample the entire contents of the package were thoroughly mixed and a representative sample taken for analysis. The results of these analyses, together with the information furnished by the manufacturers, are given in Table I. In this table the different tars are grouped according to the type of oven in which they were produced.

In columns 4 and 5 all temperatures are expressed in degrees Centigrade, although where the manufacturers gave the temperatures in degrees Fahrenheit their statements are shown in parentheses. In column 5 it will be noticed that statements relative to the maximum temperature to which the coal is brought during distillation indicate that two of the plants run below 970° C., that a total of 22 run not over 1,150° C., that 9 run from 950° C. to 1,150° C., and that only 5 run above 1,150° C. The maximum temperature of firing the retorts is, however, reported in most cases as being higher than the maximum temperature to which the coal is brought.

The maximum percentage of free carbon reported is from 16 to 24 per cent, but 17 manufacturers reported the maximum percentage of free carbon as being 12 per cent or under, and only 4 as 16 per cent or over.

Analyses of the samples received were made in accordance with the methods described in a former publication [1] of the office. The work consisted in determining the specific gravity, free carbon, or organic matter insoluble in c. p. carbon disulphide upon a 15-minute digestion at room temperature, material soluble in carbon disulphide, percentage of ash, and percentage of different fractions obtained by distilling a 250 c. c. sample in a 750 c. c. tubulated glass retort with the ther-

[1] Bulletin 38, Office of Public Roads, U. S. Department of Agriculture.

mometer so placed that the top of the bulb was level with the bottom of the juncture of the stem and body of the retort.

It will be noted that the gravities of the samples examined range from 1.133 to 1.214 and that the great majority are lower than 1.200. This in itself indicates low percentages of free carbon. The minimum percentage of free carbon was 2.73, the maximum 16.80, and the average for the 26 samples 8.38. Eighteen samples contained less than 10 per cent of free carbon and 8 more than 10 per cent. About two-thirds of these products might, therefore, be considered as low-carbon tars and the otner third as medium-carbon tars. The amount of ash in no case exceeded 0.16 per cent, and in most cases it was practically nil. This is, of course, also true of practically all gas-house coal tars. The percentage of water present varied from a trace to 10.1 per cent by volume, but in only 3 instances did it exceed 5 per cent. Water is a variable, depending upon a number of conditions, and, as it is not a part of the true tar, has been eliminated in Table II. Before leaving Table I, however, it is of interest to note that 14 of the pitch residues, remaining after distillation had been carried to 315° C., were either soft or plastic--a condition which has seldom been noticed by the author in the distillation of gas-house coal tars. The amount of solids which crystallized or precipitated out of the different fractions was found to vary greatly, as shown in the foot-notes to Table I.

TABLE II.—*Analysis of coke-oven tars upon a water-free basis.*

Serial number.	Type of oven.	Percentage of free carbon.	Fractions by weight.				
			Percentage up to 110° C.	Percentage from 110-170° C.	Percentage from 170-270° C.	Percentage from 270-315° C.	Percentage of pitch.
5126	Semet-Solvay	7.82	0.30	0.70	11.59	7.35	79.73
5123	.....do	8.84	.30	1.71	12.39	6.95	78.22
5124	.....do	7.21	1.55	.60	13.33	10.70	73.83
5137	.....do	6.19	1.21	.60	19.18	4.97	73.60
5121	.....do	4.73	1.30	.60	15.57	8.44	74.07
5125	.....do	7.49	.30	.90	20.70	8.90	68.90
5128	.....do	6.97	2.44	.31	13.81	6.05	76.51
5200	.....do	6.28	2.17	.51	16.04	10.76	70.08
5189	.....do	9.00	1.42	.20	18.10	5.79	74.36
5160	.....do	5.19	1.95	.30	16.76	6.99	73.55
5074	.....do	4.04	1.32	.81	19.89	12.75	63.87
5081	.....do	7.09	1.02	.20	14.50	8.43	75.30
5095	Otto Hoffman	14.22	2.34	.51	20.81	14.69	60.91
5083	.....do	14.69	1.46	.10	11.40	8.47	78.03
5159	.....do	11.12	1.54	.51	24.89	6.89	65.32
5107	.....do	8.62	2.57	.61	25.15	3.60	66.90
5086	United Otto	7.96	1.21	.40	10.30	9.79	78.28
5078	.....do	8.60	.91	.40	15.29	8.61	74.16
5087	.....do	5.26	.91	1.31	21.63	10.51	65.41
5109	.....do	10.63	.90	.40	23.83	6.36	68.28
5122	.....do	12.55	1.34	.30	16.39	11.44	69.89
5188	Koppers	3.95	1.21	.20	18.29	12.19	67.37
5404	.....do	2.81	1.03	.30	19.07	6.70	72.37
5108	Otto Hoffman and United Otto	11.51	1.42	.50	18.55	7.64	71.45
5127	.....do	13.52	2.50	.21	6.65	7.52	81.57
5089	United Otto and Rothberg	17.17	.30	1.73	10.12	10.42	76.68

The results given in Table II are calculated upon a water-free basis—i. e., the percentages are expressed in terms of the actual tar exclusive of water. Considering these products according to type,

it will be seen that the tar produced by the Koppers ovens contains the lowest percentage of free carbon, the Semet-Solvay tars the next lowest, the United Otto next, the Otto Hoffman next, and the mixed tar from the United Otto and Rothberg ovens contains the highest percentage of free carbon. For the sake of comparison the minimum, maximum, and average percentages of free carbon for each of these types are shown in Table III.

TABLE III.—*Percentage of free carbon in coke-oven tars.*

[Water-free basis.]

Type of oven.	Percentage of free carbon.		
	Minimum.	Maximum.	Average.
Koppers	2.81	3.95	3.38
Semet-Solvay	4.04	9.00	6.74
United Otto	5.26	12.55	9.00
Otto Hoffman	8.62	14.69	12.16
Otto Hoffman and United Otto (mixed)	11.51	13.52	12.51
United Otto and Rothberg (mixed)	17.17	17.17	17.17

The percentages of various fractions for the different types of tars overlap to such an extent that no detailed comparison will be made. The maximum, minimum, and average total distillates to 315° C. for the different types are, however, given in Table IV.

TABLE IV.—*Percentage by volume of total distillate to 315° C. in coke-oven tars.*

[Water-free basis.]

Type of oven.	Percentage by volume.		
	Minimum.	Maximum.	Average.
Koppers	30.5	36.0	33.3
Semet-Solvay	22.6	40.8	29.9
United Otto	25.6	38.5	32.6
Otto Hoffman	25.3	43.6	36.0
Otto Hoffman and United Otto (mixed)	19.9	32.1	26.0
United Otto and Rothberg (mixed)	26.9	26.9	26.9

From this Table it is evident that wide variations exist in the relation of total distillate to pitch residue in the coke-oven tars produced in this country, and this is even true of different tars produced by the same type of oven.

Straight coal-tar road binders or refined coal tars are usually manufactured by subjecting the crude material to a process of distillation with or without steam or air agitation. Distillation is carried to the point at which the residuum remaining in the still has obtained the desired consistency at normal temperatures, and this involves the removal of certain of the more volatile oils present in the crude material. For use in construction work a soft and almost fluid pitch is often produced, and the consistency of this pitch is

controlled by means of a melting point or float test. When the crude tar runs abnormally high in free carbon, it is sometimes mixed with crude water-gas tar before distillation. Water-gas tar contains a very low percentage of free carbon, and by properly proportioning the two a product is obtained, upon distillation, which does not carry more than the maximum limit of free carbon set by manufacturers. What the maximum limit should be is a much mooted question among those who have given thought to this matter. The governing considerations are: (1) What is the most economical limit from the standpoint of manufacture? and (2) What is the proper limit with regard to the utilization of the product as a road material? For a number of reasons, which it is unnecessary to mention in this circular, an excessively high-carbon tar is difficult to distill properly and, with other things equal, the lower the percentage of carbon the easier and shorter the distilling process. From this standpoint, therefore, by-product coke-oven tars are well adapted to the manufacture of road binders. Moreover, because of their low percentage of free carbon, they may be employed in a manner similar to water-gas tars, when it is desired to utilize a crude high-carbon tar in the production of a medium-carbon tar road binder.

In an ordinary road tar for use in construction work where free carbon is present to the extent of about 20 per cent, the proportion of total distillate, below 315° C., to pitch residue is approximately 1 to 4. Where this relation exists the pitch residue is hard and brittle. A residue which is soft or plastic is to be preferred, as it would indicate longer life during service, and where such a residue is present the proportion of distillate would naturally be lower for a given consistency, as the distillates may be considered as fluxes for the residues. If such is the case, it is evident from the foregoing tables that coke-oven tars offer a valuable source of supply for tar road binders. As an example, even the highest-carbon tar, No. 5089, if distilled to the point where the proportion of distillate, below 315° C., to the pitch residue was as 1 to 4, would contain less than 19 per cent of free carbon, which is at present considered as not excessive for a refined coal tar.

In conclusion it may be said that indications point strongly to the fact that by-product coke ovens will eventually play a most important part in the road-material industry, and it is to be hoped that their general adoption in this country will be rapid. The future demand for economical bituminous road binders in the United States will undoubtedly exceed the supply, and this in spite of the natural increase in petroleum and asphalt road binders. If such is the case, the present loss of enormous quantities of tar, to say nothing of gas and ammonia, because of the use of beehive ovens, is a matter worthy of the utmost consideration on the part of all who are interested in the conservation of our resources.

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Issued December 12, 1912.

U. S. DEPARTMENT OF AGRICULTURE,

OFFICE OF PUBLIC ROADS—Circular No. 98.

LOGAN WALLER PAGE, Director.

PROGRESS REPORTS OF EXPERIMENTS IN DUST PREVENTION AND ROAD PRESERVATION, 1911.

PREPARED BY THE OFFICE OF PUBLIC ROADS.

WASHINGTON
GOVERNMENT PRINTING OFFICE.
1912.

LETTER OF TRANSMITTAL.

United States Department of Agriculture,
Office of Public Roads,
Washington, D. C., April 3, 1912.

Sir: I have the honor to transmit herewith a manuscript of a circular prepared by this office entitled "Progress Reports of Experiments in Dust Prevention and Road Preservation, 1911." This is the sixth of a series of annual progress reports which give details of various experiments conducted by this office along the lines indicated by the title. Owing to the increasing interest that is manifested with regard to these publications, I recommend that this document be issued as Circular No. 98.

Paul D. Sargent,
Acting Director.

Hon. James Wilson,
Secretary of Agriculture.

CONTENTS.

PROGRESS REPORTS OF EXPERIMENTS IN DUST PREVENTION AND ROAD PRESERVATION, 1911.

INTRODUCTION.

During the year 1911 the Office of Public Roads practically completed the series of experimental sections at Ithaca, N. Y., and established a set of comparative tests at Chevy Chase, Md., and at Jamaica, N. Y. This circular contains the details of the methods pursued, together with the cost data and analyses of the materials used. The earlier work of the office along similar lines has been published in Circulars 47, 89, 90, 92, and 94, and the recent inspections of this past work will be found under the general title of "Supplementary reports," following the descriptions of the 1911 work.

EXPERIMENTS AT CHEVY CHASE, MD., 1911.

TARS AND NATIVE AND OIL-ASPHALT PREPARATIONS.

The work at Chevy Chase, Md., consisted of a series of comparative tests of bituminous binders now on the market, applied according to the specifications of the manufacturer. The road selected is an extension of Connecticut Avenue, Washington, D. C., and the work, which began at the District line at Chevy Chase Circle, extended through Chevy Chase to Bradley Lane, a distance of 3,300 feet. This road is subjected to a wide range of traffic, consisting of country and heavy automobile traffic during the entire year, and much hauling of materials of construction from the railroad station during the season favorable to building and development work.

The middle 17 feet of the road are occupied by a double-track electric-car line. The road was built 19 feet wide from the outside rail on each side with a crown of three-eighths of an inch per foot for the first 10 feet and one-half inch per foot for the remaining 9 feet. A cobblestone gutter was laid adjoining the paving. The bitumen was applied by the penetration method and the characteristics of the materials used will be found in tables at the end of this article.

The original roadway was built by dumping crushed stone and gravel into holes on the right of way as they developed under traffic until the depth of the stone finally varied from 2 inches to 14 inches on a micaceous clay subgrade. This stone was distributed so irregularly that only 140 cubic yards were saved for replacing. The old

roadway was spiked up with a steam roller, the surface broken with a plow drawn by a team, and excavation of the subgrade completed by hand. French drains 2½ feet deep, immediately under the gutters and along the car tracks, supplied underdrainage where required. As the work was done late in the season surface ditches were dug along the outside edge of the subgrade where there were no French drains to facilitate subgrade drainage during the construction.

The stone was laid and rolled in courses. The final depth of the foundation course was 5½ inches compacted, and that of the wearing course was 2½ inches compacted, except in certain places, where other figures have been given in the description of the individual sections. The size of the stone varied according to specifications for the material, but the completed thickness of all the sections was approximately 8 inches of compacted material. It was supplied in all commercial sizes at a cost of $1 per ton f. o. b. cars at the Chevy Chase siding and was hauled to the work at an additional cost of 47 cents per ton.

The bitumen was donated by the manufacturers and the freight charges were included in the project. Application of the bitumen was begun 2 feet from the outside rail to permit repairs to the car track without disturbing the finished surface. The strip between the car tracks and the bituminous work is water-bound macadam. The bitumen was applied under the direction of a representative of the manufacturer donating the binder and such minor variations from the specifications as occurred were acceptable to the manufacturer. The sections are discussed in the order of their location and the following tables show the general character of the bituminous binders used.

TABLE 1.—*Analyses of refined coal tars used at Chevy Chase, Md.*

Materials.	Light.		Heavy.	
Where used	Sec. No. 2.		Secs. 1 and 2.	
Specific gravity 25°/25° C.	1.219.		1.258.	
Float test (time)	47 seconds [1]		2 minutes 30 seconds. [2]	
Per cent of free carbon	23.35		29.60.	
	Per cent by volume.	Per cent by weight.	Per cent by volume.	Per cent by weight.
Distillation:				
Water	1.2	1.0	0.0	0.0
First light oils to 110° C.	[3] 1.0	.7	[4] .2	.2
Second light oils 110° C.–170° C.	[5] .7	.5	[4] .8	.6
Heavy oils 170° C.–270° C.	[6] 20.4	16.8	[7] 12.5	10.2
Heavy oils 270° C.–315° C.	[8] 7.4	6.5	[4] 8.9	7.5
Pitch residue	[9] 69.3	74.3	[9] 77.6	81.4
	100.0	99.8	100.0	99.9

[1] At 32° C.
[2] At 50° C.
[3] Clear.
[4] Solid.
[5] Turbid.
[6] Two-thirds solid.
[7] One-third solid.
[8] One-sixth solid.
[9] Hard, dull, brittle.

TABLE 2.—*Native and oil-asphalt products used at Chevy Chase, Md.*

Materials.	Fluxed native asphalt.	Gilsonite oil-asphalt.	Oil-asphalt.	Oil-asphalt.	Oil-asphalt.
Where used	Sec. 3.	Sec. 4.	Sec. 5.	Sec. 6.	Sec. 7.
Specific gravity 25°/25° C	1.058	0.974	0.999	0.989	0.973
Melting point ° C	46	52	74	47	90
Penetration (5 seconds, 100 grams, 25° C. [mm.])	12.80	14.60	7.30	9.40	5.50
Per cent of loss at 163° C., 5 hours (20 grams)	2.14	.87	.05	.68	.44
Penetration of residue (mm.)	[1] 5.60	[2] 9.90	[3] 6.50	[1] 7.90	[4] 5.00
Per cent of total bitumen insoluble in 86° B. paraffin naphtha	20.78	21.13	24.68	20.10	26.20
Per cent of fixed carbon	10.64	7.79	13.53	8.36	10.15
Per cent of bitumen soluble in CS_2	94.51	99.81	99.46	99.59	99.82
Organic matter insoluble	1.00	.12	.50	.28	.15
Inorganic matter	4.49	.07	.04	.13	.03
	100.00	100.00	100.00	100.00	100.00

[1] Sticky, glossy surface.
[2] Mottled surface.
[3] Sticky, slightly mottled surface.
[4] Hard, fairly lustrous.

SECTION No. 1.—REFINED COAL TAR—PENETRATION METHOD.

This section begins at the District line on the west side of Chevy Chase Circle. It is 513 feet long, of varying width, and contains 1,581 square yards.

The wearing course consisted of 3 inches of loose stone from 3 inches to 1 inch in the largest dimension. After rolling lightly, an application of 1.8 gallons of heavy refined coal tar per square yard was made at temperatures varying from 200° F. to 300° F. Screenings from $\frac{3}{4}$ inch to dust were thickly spread over the surface and the course was thoroughly rolled with a 10-ton standard type steam road roller. When the rolling was completed, all loose screenings were carefully swept into heaps with rattan hand brooms and removed. A second application of the tar of 0.8 gallon per square yard was then applied, and this in turn was covered with screenings similar to those used before. The road was then rolled until compacted.

The tar was supplied from a local plant in tank wagons heated and ready for application. The tank wagon was connected to the roller by a steam hose and the bitumen was applied to the road surface through a nozzle under pressure. Besides the roller man, two men were required to apply the bitumen.

SECTION No. 2.—REFINED COAL TAR—MODIFIED GLADWELL METHOD.

This section is 373 feet long and contains 705 square yards of treated surface. The essential difference in type between this and section 1 lies in the fact that a cushion of Potomac River sand 1 inch thick was spread evenly over the foundation course and given an application of 1.18 gallons of the light refined coal tar per square yard. After absorption of the tar by the sand, the wearing course of from 3-inch to 1-inch stone, 3 inches thick before compacting,

was spread and the surface completed as in section 1. An average of 1.95 gallons of the heavy tar per square yard was applied as the second coat, and 1.02 gallons per square yard as the seal coat. The construction was varied in that the wearing course of stone was very thoroughly compacted, so that all low spots were developed and brought to grade before applying the tar. As a consequence of this, the surface on section 2 presents a more even appearance than that of section 1.

These sections were surfaced between October 15 and October 31, 1911, and of this time there were five days on which rain fell and six on which the mornings were very foggy. The maximum temperature at 3 p. m. was 63° F., the minimum 44° F., and the mean at 3 p. m. for the period was 50° F., with the wind generally from a northerly direction.

Section No. 3.—Fluxed Native Asphalt—Penetration Method.

This section adjoins section 2 on the north. It extends from station 4 + 98 to station 13 + 21 on the west side of Connecticut Avenue and comprises 1,555 square yards.

The wearing course consisted of crushed hard limestone from 2 inches to 1 inch in size, spread 3 inches thick before being compacted.

The bitumen was applied by means of hand-pouring pots, after having been heated to a temperature of from 340° to 360° F. in 100-gallon kettles.

The first application of asphalt was made after the wearing course had been thoroughly compacted with a 10-ton road roller. It consisted of an average of 1.46 gallons per square yard. Chips ranging in size from $\frac{3}{4}$ inch to $\frac{1}{4}$ inch were applied and the surface was rolled, after which all excess of chips was removed by sweeping with rattan hand brooms. A seal coat of 0.5 gallon per square yard was then applied, covered with screenings as above, and rolled. The total amount of screenings applied was approximately 1 cubic yard to each 36 square yards of surface. Owing to a slight shortage in bitumen some of the refined semiasphaltic oil used on Bradley Lane was applied as a seal coat over the entire width of the roadway from station 4 + 98 to station 5 + 13 and over a width of 3 feet along the gutter or outer edge of the pavement from station 5 + 13 to station 6 + 63.

This section was surfaced from November 15 to November 18, 1911, inclusive, when the weather was particularly cold and raw, though fair. The maximum temperature at 3 p. m. was 55° F., the minimum 44° F., and the mean 47° F. The wind was generally from the north. Owing to heavy rains just preceding the application of bitumen to this section, it was necessary to dry all the screenings in drying pans to insure satisfactory results.

SECTION No. 4.—GILSONITE OIL-ASPHALT—PENETRATION METHOD.

Section 4 adjoins section 3 on the north. It extends from station 13+21 to station 21+44 and comprises 1,555 square yards of surfaced roadway.

The wearing course of stone consisted of particles ranging in size from 2 inches to 1 inch in diameter, spread to a depth of 3 inches before compacting. This was rolled lightly before the application of bitumen, which was poured by hand in two courses, as in the case of section 3. The first application consisted of 1.65 gallons and the second of 0.55 gallon per square yard. Screenings were spread sparingly after the first application, and brooming before applying the seal coat was considered unnecessary. The total application of screenings amounted to approximately 1 cubic yard to each 48 square yards of paving. From station 13+21 to station 17+35 chips varying in size from $\frac{3}{4}$ inch to $\frac{1}{4}$ inch were used, while over the remainder of the section screenings ranging in size from $\frac{3}{4}$ inch to dust were used. Upon completion the section was rolled with a 3-ton tandem roller.

This section was surfaced from November 3 to November 8, 1911, inclusive, and during this time the weather was cloudy and damp. Northerly winds predominated. The maximum temperature at 3 p. m. was 68° F., minimum 45° F., and mean 54° F. The screenings for this work, however, were not heated and dried.

SECTION No. 5.—OIL-ASPHALT—PENETRATION METHOD.

This section lies on both sides of the car tracks. On the west it extends from station 21+44 to station 25+82 and on the east from station 22+01 to station 25+82. It comprises 1,447 square yards of finished pavement.

The stone of the wearing course consisted of limestone crushed to sizes ranging from 2 inches to 1 inch in diameter, spread 3 inches thick before compression. It was thoroughly compacted before the application of the binder. The binder was heated to temperatures varying from 330° F. to 360° F., and applied by hand-pouring pots as in the case of section 3. The first application was at the rate of 1.69 gallons per square yard. Chips from $\frac{3}{4}$ inch to $\frac{1}{2}$ inch in diameter were then spread sparingly over this course of bitumen and the surface was thoroughly rolled. Brooming was considered unnecessary, and the second application of 0.56 gallon per square yard was poured, and was followed by chips from $\frac{3}{4}$ inch to $\frac{1}{4}$ inch in size. The surface was then rolled until firm and smooth with a standard type 10-ton road roller.

This bitumen was applied between November 27 and December 2, 1911, and during this time heavy rainfalls prevented continuous work. The weather at the time of application was cloudy and cold,

with a maximum temperature at 3 p. m. of 56° F., a minimum of 37° F., and a mean of 47° F. The prevailing wind was from the north.

All chips used on this section were heated and dried. They were applied at the rate of approximately 1 cubic yard to each 48 square yards of surface.

Section No. 6.—Oil-asphalt—Penetration Method.

This section extends from station 25+82 to station 30+20. It lies on both sides of the car tracks and comprises 1,555 square yards. The wearing course consisted of limestone crushed to sizes ranging from 3 inches to 1 inch, spread to a depth of 3½ inches before compacting, and thoroughly rolled before the application of the bitumen.

The bitumen was applied by means of hand-pouring pots as in the preceding cases and the first application amounted on the average to 1.56 gallons per square yard. Immediately following this application, the roadway was covered with a coating of chips from ¾ inch to ½ inch in size and rolled, after which it was thoroughly swept with rattan hand brooms. An application of 0.53 gallon of a harder grade of the same material was then made and this in turn was covered with chips and rolled. The screenings were spread to such thickness that 1 cubic yard covered approximately 30 square yards of surface. All the screenings for this work were heated and dried.

This section was surfaced from November 21 to November 23, 1911, while the weather was fair but cold. The maximum temperature at 3 p. m. was 50° F., minimum 41° F., and mean 45° F., with a prevailing northerly wind.

Section No. 7.—Oil-Asphalt—Penetration Method.

This section lies on the east side of the car tracks. It extends from station 16+83 to station 22+01. It is made up of two distinct tests, the first of which consisted of a one-coat application extending from station 16+83 to station 21+32, and the second of a two-coat application from station 21+32 to station 22+01.

The wearing course of stone was identical in both tests. It consisted of a layer of stone ranging from 1 inch to 2½ inches in size and spread to a depth of 3½ inches before compacting.

The application of the bitumen in two courses was similar to that of the preceding sections. The first application was made at the rate of 1.66 gallons per square yard and the second at 0.6 gallon per square yard. Chips from ¾ inch to ¼ inch in size were used sparingly between the two courses and brooming was considered unnecessary.

In the case of the one-coat test a small amount of stone chips, ranging from 1 inch to ½ inch, were spread over the surface of the

wearing course of stone after it had been thoroughly compacted, for the purpose of partially filling the coarse surface interstices and leaving the surface free from the larger irregularities due to the coarse stone. The hot oil-asphalt was then poured evenly over this surface at the rate of 1.86 gallons per square yard and followed by a layer of chips ranging from $\frac{3}{4}$ inch to $\frac{1}{4}$ inch. The section was rolled until there was no further evidence of compressibility. The total amount of chips used was approximately 1 cubic yard to 48 square yards of surface. The chips were dried before applying.

This section was surfaced on December 2 and December 5, 1911, with the temperature at 3 p. m. 46° F. and 44° F., respectively, the weather fair and the wind moderate.

The application of bitumen to this section was not supervised by the representative of the manufacturer.

On the east side a plain water-bound macadam road was built from station 16 + 83 to the District line. It is proposed to treat this with bitumens applied as surface treatment. This work will be done in May, 1912.

The cost of the work was borne by the Office of Public Roads and the tax payers' committee of section No. 2, Chevy Chase, Md.

The following unit prices prevailed:

Foreman, per day of 9 hours	\$4.00
Assistant foreman, per day of 9 hours	2.50
Roller man, per day of 9 hours	3.50
Labor, per day of 9 hours	1.75 1.60
Watchman, per week	9.00

Hand tools and small equipment, together with contractor's profit, amounted to $12\frac{1}{2}$ per cent of the total of the above-named items.

Team and driver, per day of 9 hours	\$5.00
Horse, cart, and driver, per day of 9 hours	3.00

The cost data do not include rent on roller, heating kettles, and sprinkler.

TABLE 3.—*Materials and complete cost data of Connecticut Avenue section at Chevy Chase, Md.*

SUBGRADE.

Items.	Spiking.	Excavation.	Shaping.	Rolling.	Subgrade complete.
Quantity (square yards)	....	12,903	12,903	....	12,903
Labor	$57.09	$1,426.15	$429.34	$78.54	$1,991.12
Material	24.65	....	....	27.48	52.13
Total	81.74	1,426.15	429.34	106.02	2,043.25
Cost per square yard (cents)	.63	11.05	3.33	.82	15.83
Per cent of total cost	.5	8.1	2.5	.6	11.7

DRAINAGE.

Items.	French drain. (Feet.)	8-inch bell pipe. (Feet.)	Subgrade ditches. (Feet.)	Gutters. (Feet.)	Catch basins.	Drainage system.
Quantity	3,084	465	2,980	5,741	4	....
Labor	$492.66	$73.02	$115.36	$904.75	$24.35	$1,610.14
Material	704.00	87.57	236.49	218.39	30.53	1,276.98
Total	1,196.66	160.59	351.85	1,123.14	54.88	2,887.12
Cost per square yard (cents)	9.28	1.24	2.73	8.52	.43	22.20
Per cent of total cost	6.8	.9	2.0	6.4	.3	16.4

SURFACING.

Items.	Stone on work.	Spreading stone.	Bitumen on work.	Application of bitumen.	Rolling.	Surface complete.
Quantity	[1] 4,660.6	....	....	[2] 9,377	[2] 12,903	....
Labor	....	$665.98	$85.91	$249.03	$314.01	$1,314.93
Material	$8,398.20	....	302.40	49.28	109.95	8,859.83
Total	8,398.20	665.98	388.31	298.31	423.96	10,174.76
Cost per square yard (cents)	65.05	5.16	3.01	2.32	3.28	78.82
Per cent of total cost	47.8	3.8	2.2	1.7	2.4	57.9

[1] Cubic yards. [2] Square yards.

INCIDENTAL.

Items.	Superintendence.	Watchman and lights.	Miscellaneous.	Drying stone.	Handling screenings.	Total cost.
Labor	$419.75	$202.50	$275.94	$134.20	$391.68	$6,340.26
Material	....	150.00	699.90	181.57	....	11,220.41
Total	419.75	352.50	975.84	315.77	391.68	17,560.67
Cost per square yard (cents)	3.25	2.73	7.53	2.45	3.03	135.84
Per cent of total cost	2.4	2.0	5.53	1.83	2.23	99.9

TABLE 4.—*Materials and cost data of bituminous surfaces on Connecticut Avenue section at Chevy Chase, Md.*

Section No.	Description.		Quantity of material.				Cost data (cents per square yard).																Total cost.
	Binding materials.	Area of section (square yards).	No. 2 stone (cubic yards per square yard).	Screenings (cubic yards per square yard).	Binder, first application (gallons per square yard.)	Binder, second application (gallons per square yard).	Stone on work.	Spreading stone.	Screenings on work.	Screening chips.	Drying chips.	Spreading chips.	Brooming chips.	Binder.	Freight on binder.	Hauling binder.	Hauling, placing, and cleaning kettles.	Chopping, charging, and heating bitumen.	Carrying bitumen.	Pouring bitumen.	Rolling.	Cost per square yard.	
1	Refined coal tar	1.581	0.083	0.02	1.78	0.81	15.31	1.11	4.58	......	......	0.81	1.61	20.72	......	......	......	......	......	0.50	1.54	46.18	$730.11
3	Fluxed native asphalt	1.555	.083	.03	1.46	.50	15.31	1.11	6.10	2.19	5.95	1.08	.30	22.99	3.47	1.14	0.59	1.90	0.76	.26	1.54	64.69	1,005.93
4	Gilsonite oil-asphalt	1.555	.083	.02	1.64	.55	15.31	1.11	4.58	.82	......	.81	......	24.27	4.18	1.24	.41	1.91	.65	.33	1.54	57.18	889.15
5	Oil-asphalt	1.447	.083	.02	1.69	.56	15.31	1.11	4.58	1.64	4.46	.81	......	19.58	4.34	1.27	.36	2.66	.44	.17	1.54	58.27	843.17
6	Do	1.555	.083	.03	1.56	.53	15.31	1.11	7.63	2.74	7.44	1.35	.79	21.95	4.39	1.04	.49	1.49	.73	.22	1.54	68.22	1,064.24
7	Oil-asphalt {2 coat	131	.083	.02	1.66	.60	15.31	1.11	4.58	1.64	4.46	.81	......	23.14	3.98	1.06	.25	1.52	.39	.17	1.54	59.96	78.55
	Oil-asphalt {1 coat	848	.083	.02	1.86	......	15.31	1.11	4.58	1.64	4.46	.81	......	19.05	3.27	1.06	.25	1.25	.33	.14	1.54	54.80	464.70

Section No.	Description.	Quantity of material.							Cost data (cents per square yard).													Total cost.
	Binding material.	Area of section (square yards).	Sand cushion (cubic yards per square yard).	No. 2 stone (cubic yards per square yard).	Screenings (cubic yards per square yard).	Binder, first application (gallons per square yard).	Binder, second application (gallons per square yard).	Binder, third application (gallons per square yard).	Sand on work.	Spreading sand.	Drying sand.	Stone on work.	Spreading stone.	Screenings on work.	Spreading screenings.	Brooming screenings.	Binder.	Applying binder.	Rolling.	Cost per square yard.	
2	Refined coal tar	705	0.03	0.083	0.02	1.18	1.95	1.02	4.95	0.39	0.17	15.31	1.11	4.58	0.81	1.61	33.20	0.75	1.54	64.42	$454.16

EXPERIMENTS ON BRADLEY LANE, CHEVY CHASE, MD., 1911.

OIL AND MOLASSES-LIME.

In addition to the series of tests on Connecticut Avenue extended, two experiments in surface treatment were conducted on Bradley Lane, which is a roadway crossing Connecticut Avenue at the north end of the experimental sections. It is a macadam road, which was resurfaced in the spring of 1911 and presented a smooth, well-bonded surface.

EXPERIMENT NO. 1, SECTIONS NOS. 1, 2, AND 3.—REFINED SEMIASPHALTIC OIL.

Section No. 1 begins 50 feet west of the west rail of the Connecticut Avenue car tracks. It is 811 feet long and comprises 1,216 square yards. The oil was applied at a temperature of 170° F., approximately, and was spread in two courses, the first of which consisted of 0.61 gallon per square yard and the second of 0.31 gallon per square yard. The characteristics of the material used are shown in the following table:

TABLE 5.—*Analysis of refined semiasphaltic oil [1] used in experiment No. 1 on Bradley Lane.*

Specific gravity 25°/25° C	0. 972
Viscosity, Engler 100 c. c. at 100° C. specific	9. 5
Per cent of loss at 105° C., 11 hours (20 grams)	2. 1
Per cent of loss at 163° C., 5 hours (additional)	. 68
Float test on residue [2] at 32° C. (time)	4′ 48″
Per cent of bitumen insoluble in 86° B. paraffin naphtha	8. 72
Per cent of fixed carbon	7. 36
Per cent of bitumen soluble in CS_2 (total bitumen)	99. 79
Organic matter insoluble	. 19
Inorganic matter	. 02
	100. 00

The road surface was swept with a horse-drawn rattan street sweeper, followed by hand push brooms, and was thus freed from dust and loose particles of stone. The oil was allowed to run upon the road by gravity from a tank wagon until an area of about 6 feet by 8 feet was covered. The wagon was then drawn forward a few feet, and the oil was spread and broomed into the road surface with hand push brooms. As soon as the brooming was completed, the oil was covered with chips and the surface was rolled. Six men were required to spread the oil and two to spread the chips. The chips were secured by passing crusher-run screenings ranging from ¾ inch to dust over a ¼-inch screen. In this manner both applications were made under the direction of the representative of the manufacturer.

[1] Viscous fluid, fairly sticky; contained some water.

[2] Granular surface, very viscous, fairly sticky.

Section No. 1 extends from Connecticut Avenue to the first side street leading into Bradley Lane, and a vacant lot on this side street served the purpose of a contractor's material yard. Traffic over this section may be classed as heavy, since, in addition to the mixed through traffic over Bradley Lane, there are frequently as many as 120 loads of 3 tons gross per day going to the yards and as many empty wagons returning.

Section No. 2 adjoins section 1 on the west. It is 256 feet long and comprises 384 square yards. It consists of a single application of approximately 0.61 gallon per square yard, spread and treated as described in section 1.

Section No. 3 is 1,188 feet long and comprises 1,784 square yards. Two applications of oil were made as in section 1, and the average application per square yard in the first course was 0.61 gallon and 0.31 gallon in the second.

After the surface applications were completed, all excess of oil or "bleeding" was taken up with sand and screenings ranging from ½ inch to dust. Some of this material was applied by brooming into the roadway the excess screenings which had been brushed aside by traffic, but no more screenings or chips were applied at any time than were needed to absorb the excess of oil then apparent.

The traffic over sections 2 and 3 is identical, as there are no intersecting or side streets. It may be classed as suburban traffic.

The following table of cost data for the work on Bradley Lane is based on the same unit prices as prevailed on Connecticut Avenue, and the oil was donated by the manufacturer.

TABLE 6.—*Materials and cost data of oil surface treatment on Bradley Lane, Chevy Chase, D. C.*

Section numbers	2	1 and 3
Applications	1	2
Total area covered (square yards)	384	2,999
Oil per square yard (gallon)	.61	.92
Screenings per square yard (cubic yard)	.025	.040
Cost of superintendence per square yard (cents)	.25	.40
Cost of cleaning surface per square yard (cents)	1.97	1.97
Cost of oil per square yard (cents)	2.18	3.28
Cost of freight on oil per square yard (cents)	1.02	1.55
Cost of heating oil per square yard (cents)	1.08	1.63
Cost of pumping oil per square yard (cents)	.11	.16
Cost of hauling and applying oil per square yard (cents)	.87	1.28
Cost of sand and screenings per square yard (cents)	4.50	7.20
Cost of screening chips per square yard (cents)	.67	.98
Cost of spreading sand and chips per square yard (cents)	1.11	1.64
Cost of brooming chips per square yard (cents)	.23	.45
Cost of rolling per square yard (cents)	.52	1.04
Total cost per square yard (cents)	14.51	21.58
Total cost of entire section	$55.72	$647.18

EXPERIMENT No. 2, SECTION No. 4.—MOLASSES-LIME.

In Circular No. 90 may be found the details of a successful experiment at Newton, Mass., in which a mixture of molasses, oil, and lime was used as the binding material for a crushed-rock aggregate in road construction by the mixing method. Mention is also made of an experiment in which a weak preparation of molasses and lime was applied to a macadam surface over which sand had first been spread, but as this experiment proved a failure no details are given.

The theory upon which this method of treatment was based depends upon the fact that a mixture of molasses and lime results in the formation of calcium sucrates, which are tough, sticky salts, rather sparingly soluble in water.

Laboratory results from properly proportioned mixtures of lime, molasses, and rock dust or clay have shown that the salts formed are capable of developing a remarkably high binding value, and since waste molasses or black strap is obtained at a comparatively low figure in the neighborhood of sugar refineries it was thought that an economic and efficient method of surface treatment for such localities might be developed and that the experiment which had previously failed might be well worth another trial under somewhat different conditions.

The section selected was 1,060 feet in length and adjoins the west end of section 3, on which oil was used. The road surface was well bonded and in good condition. Before treating the excess of dust and detritus was swept off and the surface was given a light sprinkling with water to lay and saturate the remaining dust.

Basing a formula on some experimental results in the laboratory, the materials for treatment were mixed in the proportion of 360 pounds of lime, 150 gallons of molasses, and sufficient water to dilute the above mixture to 450 gallons, which was the capacity of the sprinkler used. This made a sticky mixture, but one that could be run from an ordinary sprinkler quite readily. The method of operation was crude, and as the work was done in December difficulty in mixing was largely increased by the cold weather and consequent viscosity of the molasses. The lime was slaked in barrels to form a thick cream, and to each half barrel of this cream a half barrel of molasses was added with constant stirring. It was hoped that a small rotary hand pump could be used to force the material up into the sprinkler, but it failed from the start, and as no other facilities were at hand the mixture had to be bailed with long-handled dippers. When it had all been transferred from the barrels, water was added up to the capacity of the sprinkler, and the solution was immediately sprayed on the road in sufficient quantity to saturate the surface thoroughly. The application was made heaviest on the crown of the road and any excess drained off toward the shoulders.

The surface dried quite rapidly, and there was no interruption to traffic. When inspected, about one month after treatment, the surface still showed evidences of having been treated, although there had been several heavy rains previous to the inspection. It is hoped to continue the experiment with one or more applications during the coming summer.

The total area treated was 1,531 square yards, and the cost data were as follows:

TABLE 7.—*Cost data of molasses-lime experiment at Chevy Chase, Md.*

Labor, for sweeping, 2½ hours, at 20 cents	$0.50
Labor, for mixing, etc., 16 hours, at 20 cents	3.20
Team, for sprinkling, ½ day, at $5	2.50
Lime, 360 pounds, at 90 cents per 100 pounds, delivered on work	3.24
Molasses, 150 gallons, at 15 cents per gallon, delivered on work	22.50
Total cost of treatment	31.94
Total cost per square yard	.02

EXPERIMENTS AT JAMAICA, N. Y., 1911.

OIL-CEMENT CONCRETE, OIL ASPHALT, TAR AND FLUXED NATIVE ASPHALT.

The experiments at Jamaica were conducted during August and September, 1911, by the Office of Public Roads, in cooperation with the Bureau of Highways, Borough of Queens, New York City. The general plan of cooperation provided that all materials and appliances for handling them and all labor requisite for efficiently conducting the experiments should be supplied by the Borough of Queens. It was also provided that at least one competent foreman and one engineer employed by the Bureau of Highways of the Borough of Queens should be in constant attendance while the work was under way and that one or more engineers should be assigned by the Office of Public Roads to assist in supervising the work and to check all materials and cost data. Specifications for materials and methods of construction were drawn by a committee appointed by the borough president, which had entire and exclusive jurisdiction over the section of Hillside Avenue upon which these experimental sections of pavement were laid, and this jurisdiction is to continue during the period of maintenance and observation.

The work consisted in resurfacing a section of Hillside Avenue, 2,000 feet in length, beginning at the N. Y. & Q. C. Street Railway crossing near Flushing Avenue and extending east to Bergen Avenue.

In 1895 this section of Hillside Avenue was surfaced to a width of 18 feet with 6-inch water-bound trap rock macadam, and the shoulders, 17 feet in width on each side, were surfaced with gravel of a maximum size of 5 inches in diameter. Brick gutters, 4 feet in width, were laid on each side.

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In 1905 this section was scarified and resurfaced with water-bound macadam, and a strip $3\frac{1}{2}$ feet wide was added to each side, making the total width of macadam road 25 feet. The surfacing consisted of $2\frac{1}{2}$-inch trap rock laid 5 inches deep, measured loose. Sand was used to fill the voids partially and trap-rock screenings were used as the binder.

When the experimental work was begun in August, 1911, the center of the road had worn down so that the crown was nearly flat. There were also a number of pot holes, some due to street openings which had been made from time to time and others due to the wear and tear of traffic.

The entire road was scarified to a depth of about 3 inches, brought to a crown of about $\frac{3}{8}$ inch per foot with a road grader, and properly shaped by hand labor. Except in section 1, a course of $1\frac{1}{2}$-inch stone, about $1\frac{1}{2}$ inches deep, was then spread over the entire road and the whole thoroughly rolled.

Brick and granite block headers were placed along the sides of the oil-cement concrete section, and a single course of cobbles 3 to 5 inches in diameter was set by hand to form a shoulder for the greater part of the bituminous pavements.

On the foundation thus prepared nine experimental surfaces were laid: One oil-cement concrete pavement, four bituminous-concrete pavements, and four bituminous-macadam pavements. The aggregate used in all the experiments was clean, crushed trap rock, screened according to the following grades:

Screenings.—That product of the ordinary run of the crusher passing a $\frac{1}{2}$-inch or $\frac{5}{8}$-inch circular opening, including the dust of fracture.

Three-fourths-inch stone.—Crushed rock passing the $1\frac{1}{8}$-inch or $1\frac{1}{4}$-inch opening, but retained on the $\frac{1}{2}$-inch or $\frac{5}{8}$-inch opening.

One and one-half-inch stone.—Crushed rock passing the $2\frac{1}{4}$-inch opening, but retained on the $1\frac{1}{8}$-inch or $1\frac{1}{4}$-inch opening.

Three-eighths-inch stone.—Screenings which are screened to remove practically all stone dust by passing over a $\frac{1}{4}$-inch or $\frac{3}{8}$-inch screen.

The following table of tests on representative samples shows the average grading of material received on the work.

TABLE 8.—*Tests of crushed rock.*

Materials.	$\frac{3}{4}$-inch stone. (Percentage.)	$\frac{3}{8}$-inch stone. (Percentage.)	Stone screenings. (Percentage.)
Retained on 1-inch screen	1.2	....	....
Retained on $\frac{3}{4}$-inch screen	13.7	....	....
Retained on $\frac{1}{2}$-inch screen	37.5	....	....
Retained on $\frac{1}{4}$-inch screen	40.3	46.0	14.8
Retained on $\frac{1}{8}$-inch screen	5.4	50.2	35.9
Passing $\frac{1}{8}$-inch screen	1.9	3.8	49.3

The equipment consisted of a concrete mixer with arrangement for heating the aggregate, a patented distributor with 350-gallon tank, and a 375-gallon heating kettle. These were loaned by the manufacturers. The 10-ton steam roller, small kettles, pouring pots, and tools were furnished by the Borough of Queens. The labor was furnished from the regular city force, which, with few exceptions, was composed of inexperienced and unsatisfactory workmen, and this fact is undoubtedly responsible for higher costs than should be the case for this class of work.

EXPERIMENT No. 1.—OIL-CEMENT CONCRETE.

Beginning with station 0 (at the N. Y. & Q. C. R. R.), this section extends to station 1+73 and includes the south intersection with Flushing Avenue. The concrete was made up of 1 part by volume of Portland cement, 2 parts of sand, and 4 parts of stone, which was hard trap rock ranging in size from $\frac{3}{4}$ inch maximum to $\frac{1}{4}$ inch minimum diameter, and oil was added to the amount of 10 per cent, by weight, of the cement. The materials were mixed in a mechanical concrete mixer, and the most satisfactory results were obtained by the following procedure for each batch. About 3 gallons of water were put into the skip, followed by a barrow of stone, a barrow of sand, a bag of cement, and a barrow of stone in the order mentioned. The stone was leveled down and the balance of the water necessary to form a wet concrete was added. The measured amount of oil was then poured over the wet stone, after which the skip was elevated and the contents were dumped into the drum and thoroughly mixed. The concrete was conveyed and dumped in place by wheelbarrows. It was placed to a depth of 4 inches uncompacted in a single uniform layer across the entire width of and at right angles to the center line of the road. The surface was tamped with concrete tampers until water flushed to the surface. Any uneven places which developed were filled with trap-rock screenings,[1] and the first 12.5 feet of the section were finished by spreading a thin coat of these screenings over the wet surface. The remainder of the section was finished by spreading over the tamped concrete a mortar composed of 2 bags of cement, 2.5 cubic feet of sand, 7.5 cubic feet of screenings, and 8 quarts of oil. Square joints were formed between the days' work by butting the concrete against oiled 2×4 scantling.

From station 0 to station 0+97.2, a residual oil showing the characteristics under No. 1 in Table 9 was used, while the product of another manufacturer, and represented under No. 2, was used on the remainder of the section. The two parts of the section were separated by an expansion joint consisting of two courses of 3-inch

[1] See Table No. 8.

wood block, laid on a sand cushion and filled with the fluxed native asphalt used in experiment No. 3.

The section was closed to traffic for 28 days and was kept wet during the first 7 days of that period.

TABLE 9.—*Analyses of residual oils used in experiment No. 1.*

	(1)[1]	(2)[1]
Specific gravity 25°/25° C.	0.935	0.922
Viscosity, Engler, 100 c. c. at 50° C., specific	49.20	14.40
Per cent of loss at 163° C., 5 hours (20 grams)	1.19	2.91
Per cent of total bitumen insoluble in 86° B. paraffin naphtha	3.13	1.94
Per cent of fixed carbon	3.04	2.42
Per cent of bitumen soluble in CS_2 (total bitumen)	99.89	99.95
Organic matter insoluble	.11	.03
Inorganic matter insoluble	.00	.02
Total	100.00	100.00

[1] Fluid, greasy.

TABLE 10.—*Tests of Portland cement used in experiment No. 1.*

Specific gravity 25°/25° C.	3.11
Per cent of water for normal consistency	21.00
Initial set	2′ 15″
Final set	3′ 40″
Fineness:	
Per cent retained on 200-mesh sieve	20.6
Per cent retained on 100-mesh sieve	3.6
Pat in air 28 days	Sound.
Pat in water 28 days	Sound.
Pat steamed 5 hours	Sound.
Tensile strength:	
Neat 24 hours	443 pounds per square inch.
Neat 7 days	691 pounds per square inch.
Neat 28 days	651 pounds per square inch.
1:3 Standard Ottawa sand 7 days	376 pounds per square inch.
1:3 Standard Ottawa sand 28 days	483 pounds per square inch.
Per cent of magnesia (MgO)	3.05
Per cent of sulphur trioxide (SO_3)	1.05

TABLE 11.—*Test of sand used in experiment No. 1.*

Per cent retained on 8-mesh screen	7.4
Per cent retained on 10-mesh screen	5.2
Per cent retained on 20-mesh screen	17.1
Per cent retained on 30-mesh screen	20.6
Per cent retained on 40-mesh screen	19.9
Per cent retained on 50-mesh screen	9.8
Per cent retained on 80-mesh screen	13.9
Per cent retained on 100-mesh screen	2.0
Per cent retained on 200-mesh screen	1.8
Passing 200-mesh screen	2.3
Total	100.0
Silt (by volume)	4.3

EXPERIMENT NO. 2.—CUT-BACK OIL-ASPHALT—MIXING METHOD.

This section adjoins the oil-cement-concrete section and is 299 feet in length, extending from station 1+97 to station 4+96. The machine mixer was used and the charge for each batch consisted of 7.5 cubic feet of the $\frac{3}{4}$-inch stone and 5.5 gallons of bitumen. Owing to considerable wet weather, the stone was frequently quite wet, and time was lost in drying it for three or four minutes by means of the hot-blast before the addition of the binder. The bitumen was melted in a 375-gallon tar kettle and heated to a temperature of about 240° F. before being poured into the skip of the mixer. The mixed aggregate was taken to the road in wheelbarrows and evenly spread on the foundation with rakes to insure a thickness of 2 inches after rolling. The rolling was done on the day following that on which the mixture was laid, and in portions of the experiment there was considerable rainfall before the rolling took place. The characteristics of the bituminous binder used are shown in Table 12.

Owing to delay and a period of rainy weather, the application of a seal coat to this section was delayed for two weeks. The surface was then swept clean and an application of a heavy oil-asphalt, an analysis of which is also shown in Table 12, was applied by means of the distributor. The application was not as uniform as might be desired, and it was necessary to touch up with pouring pots a number of bare spots that were missed by the distributor when it became clogged. The seal coat was immediately followed by a layer of $\frac{3}{8}$-inch stone, after which the surface was well rolled.

TABLE 12.—*Analyses of bituminous binders used in experiment No. 2.*

	Cut back oil-asphalt.[1]	Oil-asphalt.[2]
Specific gravity 25°/25° C	0.981	1.002
Melting point °C	....	72.00
Penetration (5 seconds, 100 grams, 25°C. [mm.])	....	4.80
Viscosity °Engler 50 c. c. at 100° C. (time) ... seconds	324.60	....
Flash point °C	149.00	....
Burning point °C	194.00	....
Per cent of loss at 163° C., 5 hours (20 grams)	9.12	.18
Penetration of residue:		
(5 seconds, 100 grams, 25° C. [mm.])	18.60	4.2
(5 seconds, 100 grams, 4° C. [mm.])	....	1.2
Per cent of total bitumen insoluble in 86° B. paraffin naphtha	17.02	25.52
Per cent of bitumen insoluble in CCl_4	.00	.00
Per cent of fixed carbon	7.10	9.99
Per cent of paraffin scale	.12	.14
Per cent of bitumen soluble in CS_2 (total bitumen)	99.68	99.64
Organic matter insoluble	.15	.25
Inorganic matter insoluble	.17	.11
Total	100.00	100.00

[1] Sticky, very viscous. [2] Sticky, semisolid.

Experiment No. 3.—Fluxed Native Asphalt—Mixing Method.

This section adjoins the one just described and is 304 feet in length, extending from station 4+96 to station 8+0. The method of construction was the same as in experiment No. 2, excepting for the fact that the seal coat was applied entirely with pouring pots. Considerable delay was occasioned by rain and consequent wet stone. The bitumen required more heating than that used in the previous experiment, and an average temperature of 340° F. was maintained in the heating kettle.

The characteristics of the material used in both the mixing and seal coat are shown in the following table:

Table 13.—*Analysis of fluxed native asphalt* [1] *used in experiment No. 4.*

Specific gravity 25°/25° C	1.045
Penetration (5 seconds, 100 grams, 25° C. [mm.])	13.00
Per cent of loss at 163° C., 5 hours (20 grams)	3.31
Penetration of residue (as above)	5.50
Per cent of total bitumen insoluble in 86° B. paraffin naphtha	22.49
Per cent of fixed carbon	10.96
Per cent of bitumen soluble in CS_2 (total bitumen)	95.11
Organic matter insoluble	2.01
Inorganic matter insoluble	2.88
Total	100.00

Experiment No. 4.—Refined Coal Tar—Mixing Method.

This section adjoins the one just described and is 298 feet in length, extending from station 8+0 to station 10+98. The same method of construction as described under experiment No. 2 was pursued, and a refined coal tar having the characteristics shown in the following table was used. Each batch consisted of 10 cubic feet of stone and 7 gallons of binder.

Table 14.—*Analysis of refined coal tar* [2] *used in experiment No. 4.*

Specific gravity 25°/25° C		1.253
Float test at 50° C. (time)		1′51″
Per cent of free carbon (insoluble in CS_2)		22.42
Distillation:	Per cent by volume.	Per cent by weight.
Water	0.0	0.0
First light oils to 110° C	.0	.0
Second light oils 110–170° C	[3] 1.2	.9
Heavy oils 170–270° C	[4] 17.6	15.1
Pitch residue	[5] 81.2	83.8
Total	100.0	99.8

[1] Sticky, granular, semisolid.
[2] Very viscous fluid.
[3] Solid.
[4] Three-quarters solid.
[5] Hard, dull, brittle.

With a view to determining the relative value of coal tar and oil asphalt for a seal coat, the section was divided into two parts, and these subdivisions have been treated separately in the cost data. For the first 150 feet of the section a seal coat of the tar used in the construction was employed, while the remaining 148 feet were covered with a seal coat of the oil-asphalt used in experiment No. 2 and shown in Table 12. The application of both materials was made with pouring pots.

Experiment No. 5—Cut Back Oil-Asphalt—Mixing Method.

This section adjoins experiment No. 4, and is 296 feet in length, extending from station 10+98 to station 13+94. The experiment is in every way identical with experiment No. 2, excepting that a similar type of material from another manufacturer was used, and the seal coat was of the same material as was used in the aggregate. The bitumen was all applied with pouring pots. The analysis of the bituminous binder used was as follows:

Table 15.—*Analysis of cut back oil-asphalt[1] used in experiment No. 5.*

Specific gravity 25°/25° C.	0.988
Penetration (5 seconds, 100 grams, 25° C. [mm.])	19.70
Flash point °C.	165.00
Burning point °C. did not burn at	300.00
Per cent of loss at 163° C., 5 hours (20 grams)	5.20
Penetration of residue (as above)	6.90
Per cent of total bitumen insoluble in 86° B. paraffin naphtha	21.47
Per cent of total bitumen insoluble in CCl_4	.13
Per cent of fixed carbon	12.79
Per cent of bitumen soluble in CS_2 (total bitumen)	99.20
Organic matter insoluble	.68
Inorganic matter insoluble	.12
Total	100.00

The material mixed well in batches of 10 cubic feet of stone to 7 gallons of bitumen, and owing to improved organization of labor and more favorable weather conditions, the cost was lower than that of experiment No. 2.

Experiment No. 6.—Oil-Asphalt—Penetration Method.

This section adjoins experiment No. 5 and is 156 feet in length, extending from station 13+94 to station 15+50.

The general method of construction was to spread over the prepared foundation a single course of the 1½-inch stone to a depth of 3 inches, loose measurement. The course was rolled sufficiently without sprinkling to compact the fragments of stone, leaving the

[1] Sticky, semisolid.

surface open enough to allow the hot bitumen to penetrate. The application of all the bitumen in this experiment was made by pouring pots and at the rate of 1½ gallons per square yard. The first application was immediately followed by an application of sufficient ⅜-inch stone to fill the surface voids completely, and the road was at once thoroughly rolled until solid.

The bitumen, an analysis of which is given below, was used for the first application on the entire section and for a seal coat on the eastern half of it. As there was not sufficient of this material to finish the section, a seal coat of the oil-asphalt used in experiment No. 2 and shown in Table 12 was applied to the western half. This was immediately followed by a light application of ⅜-inch stone and thorough rolling.

TABLE 16.—*Analysis of oil-asphalt*[1] *used in experiment No. 6.*

Specific gravity 25°/25° C	0. 996
Penetration (5 seconds, 100 grams, 25° C. [mm.])	17. 00
Per cent of loss at 163° C., 5 hours (20 grams)	. 50
Penetration of residue (as above)	14. 10
Per cent of total bitumen insoluble in 86° B. paraffin naphtha	18. 62
Per cent of total bitumen insoluble in CCl_4	. 00
Per cent of fixed carbon	8. 29
Per cent of paraffin scale	. 14
Per cent of bitumen soluble in CS_2 (total bitumen)	99. 78
Organic matter insoluble	. 17
Inorganic matter insoluble	. 05
	100. 00

EXPERIMENT NO. 7.—REFINED COAL TAR—PENETRATION METHOD.

This section adjoins experiment No. 6 and is 150 feet in length, extending from station 15 + 50 to station 17 + 0.

The method of construction was exactly the same as described under experiment No. 6, excepting for the fact that all the bitumen was applied by means of the distributor. The refined coal tar used in experiment No. 4, an analysis of which is given in Table 14, was used. An 8-barrel open pan and two 2-barrel kettles were used for heating the tar before it was pumped into the distributor, and the temperature of the material at the time of application ranged from 260° F. to 270° F.

EXPERIMENT NO. 8.—FLUXED NATIVE ASPHALT—PENETRATION METHOD.

This section adjoins experiment No. 7 and is 150 feet in length, extending from station 17 + 0 to station 18 + 50. The method of construction and application was the same as in the preceding experiments, and the fluxed native asphalt that was used was the same as was used in experiment No. 3. The bitumen was applied by the distributor, and the average temperature of the material at the time of application was about 330° F.

[1] Sticky, semisolid.

Experiment No. 9.—Oil-Asphalt—Penetration Method.

This is the last section and adjoins experiment No. 8. It is 150 feet in length, extending from station 18 + 50 to station 20 + 0.

The experiment was carried out in exactly the same manner as the preceding one, with an oil-asphalt, the analysis of which is given in Table 17. The application was made by means of the distributor, and the average temperature of the bitumen while being applied was 335° F.

Table 17.—*Analysis of oil-asphalt*[1] *used in experiment No. 9.*

Specific gravity 25°/25° C	0.996
Penetration (5 seconds, 100 grams, 25° C. [mm.])	11.60
Per cent of loss at 163° C., 5 hours (20 grams)	.21
Penetration of residue (as above)	7.40
Per cent of total bitumen insoluble in 86° B. paraffin naphtha	23.28
Per cent of total bitumen insoluble in CCl_4	.04
Per cent of fixed carbon	12.82
Per cent of bitumen soluble in CS_2 (total bitumen)	99.41
Organic matter insoluble	.50
Inorganic matter insoluble	.09
	100.00

Shortly after the sections were completed, a traffic census covering a period of 11 days under average conditions showed a maximum of 2,794 and a minimum of 655 vehicles, or an average of 1,493 for a period of 24 hours. This included practically every form of vehicle, from light pleasure carriage to heavy motor dray, but approximately 75 per cent was motor driven. During the aero meet at Belmont Park, the number of automobiles for one period of 24 hours was 5,808.

When last inspected in December, the surfaces all presented an excellent appearance.

In making up the tables of cost data, the following unit prices were used:

Foreman, per day of 8 hours	$4.00
Assistant foreman, per day of 8 hours	3.25
Roller man, per day of 8 hours	4.50
Engineer for mixer, per day of 8 hours	4.50
Laborer, per day of 8 hours	2.50
Watchman, per day of 8 hours	2.50
Horse and cart, with driver, per day of 8 hours	3.50
Team, with driver, per day of 8 hours	6.00
Roller, with engineer, per day	10.00
Scarifier, per day	4.00
Heating kettles, 400 gallons capacity per day	.30
Heating kettles, 140 gallons capacity per day	.15
Small tools, per day per man	.03

The cost data do not include any charge for the use of the mixer or distributor.

[1] Sticky, semisolid.

TABLE 18.—*Materials and cost data of oil-cement-concrete experiment at Jamaica, N. Y.*

Experiment No.	Description. Oil.	Length of section (feet).	Area of section (square yards).	Quantities of materials. ¾-inch stone (cubic yards per square yard).	Sand (cubic yards per square yard).	Cement (barrels per square yard).	Screenings (cubic yards per square yard).	Oil (gallons per square yard).	Cost data (cents per square yard). Preparing foundation.	¾-inch stone.[1]	Screenings.[1]	Sand.[1]	Cement.[1]	Oil.[1]	Mixing and laying.	Superintendence.	Watchmen.	Miscellaneous.	Total cost. Cents (per square yard).	Entire section.
1A	Residual petroleum No. 1	97.2	269.9	0.091	0.049	0.140	0.009	0.650	12.30	24.13	2.38	4.33	18.84	4.73	34.00	6.73	14.09	7.06	128.59	$347.06
1B	Residual petroleum No. 2	75.8	301.4	.091	.049	.140	.009	.700	12.30	24.13	2.38	4.33	18.84	4.57	34.00	6.73	14.09	7.06	128.43	387.10

[1] Delivered on work.

TABLE 19.—*Materials and cost data of experiments at Jamaica, N. Y.*

MIXING METHOD.

Experiment No.	Description: Bituminous binder.	Description: Length of section (feet).	Description: Area of section (square yards).	Quantities of materials: 1½-inch stone (cubic yards per square yard).	Quantities of materials: ¾-inch stone (cubic yards per square yard).	Quantities of materials: ⅜-inch stone (cubic yards per square yard).	Quantities of materials: Binder in mix (gallons per square yard).	Quantities of materials: Binder in seal coat (gallons per square yard).	Cost data (cents per square yard): 1½-inch stone.[1]	Cost data: Preparation.	Cost data: ¾-inch stone.[1]	Cost data: ⅜-inch stone.[1]	Cost data: Binder in mix.[1]	Cost data: Binder in seal coat.[1]	Cost data: Preparing and laying mix.	Cost data: Heating and applying seal coat.	Cost data: Spreading ⅜-inch stone.	Cost data: Rolling.	Cost data: Superintendence.	Cost data: Watchmen.	Cost data: Miscellaneous.	Total cost—Cents (per square yard).	Total cost—Entire section.	Total cost—Foundation and wearing surface (cents per square yard).	Total cost—Entire section—foundation and wearing surface.
2–5	Foundation	1,197	3,325.0	0.038					10.10	12.30												22.40	$744.80		
2	Cut-back oil-asphalt	299	830.5		0.082	0.017	1.61	0.72			21.63	4.50	18.56	8.31	22.48	1.94	1.32	5.44	6.73	14.09	7.06	112.06	930.66	134.46	$1,116.69
3	Fluxed native asphalt	304	844.5		.088	.017	1.73	.82			23.18	4.50	23.04	10.93	22.46	1.20	1.27	5.43	6.73	14.09	7.06	119.89	1,012.47	142.29	1,201.64
4	Refined coal tar[2]	150	417.0		.090	.017	1.69	.79			23.78	4.50	16.92	7.92	15.86	.84	.88	5.43	6.73	14.09	7.06	104.01	433.72	126.41	527.13
	Do.[3]	148	411.0		.090	.017	1.69	.70			23.78	4.50	16.92	8.05	15.86	.86	.88	5.43	6.73	14.09	7.06	104.16	428.10	126.56	520.16
5	Cut-back oil-asphalt	296	822.0		.085	.017	1.60	.75			22.45	4.50	14.08	6.60	15.57	1.23	.69	5.43	6.73	14.09	7.06	98.43	809.09	120.83	993.22

[1] Delivered on work. [2] Coal-tar, seal coat. [3] Oil-asphalt, seal coat.

PENETRATION METHOD.

Experiment No.	Description: Bituminous binder.	Description: Length of section (feet).	Description: Area of section (square yards).	Quantities of materials: 1½-inch stone (cubic yards per square yard).	Quantities of materials: ⅜-inch stone (cubic yards per square yard).	Quantities of materials: Binder, first application (gallons per square yard).	Quantities of materials: Binder, seal coat (gallons per square yard).	Cost data (cents per square yard): 1½-inch stone delivered on work.	Cost data: Preparation and spreading 1½-inch stone.	Cost data: ⅜-inch stone delivered on work.	Cost data: Binder.	Cost data: Heating and applying binder.	Cost data: Spreading ⅜-inch stone.	Cost data: Rolling.	Cost data: Superintendence.	Cost data: Watchmen.	Cost data: Miscellaneous.	Total cost—Cents (per square yard).	Total cost—Entire section.	Total cost—Foundation and wearing surface (cents per square yard).	Total cost—Entire section—foundation and wearing surface.
6–9	Foundation	606.0	1,684.3	0.038				10.10	12.30									22.40	$377.28		
6	Oil-asphalt	156.0	433.3	.083	0.025	1.52	0.77	22.00	3.67	6.63	26.33	4.27	1.26	5.16	6.73	14.09	7.55	97.69	423.29	120.09	$520.35
7	Refined coal tar	150.0	417.0	.083	.025	1.54	.94	22.00	3.67	6.63	24.89	5.25	5.62	5.16	6.73	14.09	7.55	101.59	423.63	123.99	517.03
8	Fluxed native asphalt	150.0	417.0	.083	.025	1.50	1.04	22.00	3.67	6.63	33.78	7.41	3.67	5.16	6.73	14.09	7.55	110.69	461.58	133.09	554.98
9	Oil-asphalt	150.0	417.0	.083	.025	1.53	1.15	22.00	3.67	6.63	22.91	6.81	2.79	5.16	6.73	14.09	7.55	98.38	410.08	120.74	503.48

EXPERIMENTS AT ITHACA, N. Y., 1911.

OIL-ASPHALT, REFINED ASPHALTIC PREPARATION, REFINED COAL TAR.

The following experiments at Ithaca were a continuation of those conducted in 1909 and 1910 by the Office of Public Roads in cooperation with Cornell University and described in Circulars Nos. 92 and 94. The work for 1911 consisted in resurfacing section 25 on East Avenue, the surface of which had almost completely disintegrated during the winter, in completing the area allotted to experiment No. 16 in 1910, on which the work was interrupted by bad weather, and in constructing two new sections on South Avenue. In addition to this, all necessary repairs were made on the sections which had been previously constructed. Work began on July 10 and continued until August 12, 1911. A total of 757 linear feet of surface was completed, but considerable time was lost in waiting for materials.

In accord with previous arrangements, the university furnished all stone, machinery, and necessary labor. The bituminous binders were donated by the manufacturers, with the exception of the refined coal tar used in experiment No. 27, which was purchased by the university, and the freight charges on donated materials were paid by the Office of Public Roads.

The two sections designated as No. 29 and No. 30 extend west on South Avenue from the car-track crossing to the intersection with Central Avenue. The foundation was an old macadam road which had been rough and uneven, and this was spiked up with the roller and harrowed with a spring-tooth harrow in order to bring the coarse material to the surface. The old material was redistributed in order to produce a uniform grade, after which the foundation was rolled until firm. A course of broken stone ranging in size from 1 to 2½ inches was then spread over the road to a depth of approximately 2½ inches and a width of 20 feet and rolled. On the foundation thus prepared the wearing surface was laid 16 feet in width.

The working equipment was the same as that used for previous experiments and consisted of a 10-barrel tank fitted with a fire box for heating the bitumen. A 2-barrel iron soap kettle was also used for repair work. The mixing plant was located at East Ithaca, about 2,000 feet from the road, and consisted of four flat stone heaters having a heating surface of from 75 to 80 square feet, and a semicylindrical section of a boiler for heating screenings. The mixing was done in a portable concrete mixer of the old McKelvey type. Wheelbarrows were used for measuring and transporting the stone at the mixing plant, and the mixed aggregate was conveyed to the site of the work in dump wagons.

The labor employed was unskilled, and consisted of the regular campus force, together with a few extra men. Common labor was figured at $1.75 per 9-hour day, double teams at $4, engineer for mixer at $4, and roller at $3 per day. Scrap wood was used for heating the kettles and coal for the roller cost $3 per ton. The stone used was a hard limestone, costing $1.20 per ton f. o. b. cars at siding at East Ithaca.

As noted in previous experiments, the cost of construction was excessive owing to crude apparatus, unskilled labor, and the expense of preparation for such a small amount of work.

Experiment No. 24, Section No. 29.—Oil-Asphalt—Mixing Method.

The section treated in this experiment is 300 feet in length and begins at station 22, where the car track crosses South Avenue. A course of broken limestone, ranging in size from 1 to 2½ inches, was laid to a depth of approximately 2½ inches on the foundation and rolled until firm.

The wearing surface was proportioned and prepared as follows: Six parts by weight of stone ranging from 1 to 2½ inches in size to one part of from ½ to ¾ inch stone chips were measured in wheelbarrows and carried to the mixer. The coarse stone was dumped into the mixer first and about 6 per cent of the total aggregate by weight of hot bitumen was added. After the mixer had made a few turns, the stone chips were dumped in and the mixing continued until the stone had become thoroughly covered with bitumen. The mixed aggregate was then dumped into a wagon and taken to the road. It was deposited on a dumping board, from which it was spread to a depth of from 2½ to 3 inches over the foundation. The stone ran a little larger than desirable at times, and when this occurred the proportion of stone chips had to be increased.

This course was well rolled after a light coat of clean stone chips from ½ to ¾ inch in size had been spread over the surface to fill the voids partially and keep the mixture from sticking to the roller. When thoroughly rolled, a seal coat of about a half gallon of bitumen to the square yard was applied. Enough stone chips were then added to take up all surplus bitumen and fill the surface voids, after which the surface was thoroughly rolled.

The characteristics of the oil-asphalt used in this experiment are shown in the following table:

Table 20.—*Analysis of oil-asphalt* [1] *used in experiment No. 24.*

Specific gravity 25°/25° C	0.996
Melting point ° C	57.50
Penetration (5 seconds, 100 grams, 25° C. [mm.])	9.70
Per cent of loss at 163° C., 5 hours (20 grams)	1.91
Penetration of residue (as above)	6.70

[1] Dense, sticky, semisolid.

Per cent of total bitumen insoluble in 86° B. paraffin naphtha	24.19
Per cent of fixed carbon	9.10
Per cent of bitumen soluble in CS_2 (total bitumen)	99.77
Organic matter insoluble	.14
Inorganic matter insoluble	.09
	100.00

When last inspected in October, this section was in excellent condition and presented a uniformly smooth, hard surface.

Experiment No. 25, Section No. 25.—Oil-Asphalt—Mixing Method.

The section treated in this experiment is 296 feet long, extending from station 16+10 to station 19+6. It was originally constructed in 1910, but owing to the fact that the bitumen proved too hard, the surface rapidly went to pieces and the road had to be resurfaced. The old surface was therefore spiked up with the roller and harrowed with a spring-tooth harrow. It was then rolled until firm, after which the new wearing surface was mixed, laid, and finished exactly as in the preceding experiment. The bitumen used in this section was not wholly satisfactory, owing to the fact that some drums were very soft, while others were quite hard; but by mixing the two a fairly uniform material was secured.

The characteristics of an average sample are shown in the following table.

Table 21.—*Oil-asphalt*[1] *used in experiment No. 25.*

Specific gravity 25°/25° C	1.001
Penetration (5 seconds, 100 grams, 25° C. [mm.])	19.10
Per cent of loss at 105° C., 7 hours (20 grams)	.28
Per cent of loss at 163° C., 5 hours (additional loss)	1.01
Penetration of residue (as above)	9.00
Per cent of total bitumen insoluble in 86° B. paraffin naphtha	24.70
Per cent of fixed carbon	15.42
Per cent of bitumen soluble in CS_2 (total bitumen)	99.58
Organic matter insoluble	.42
Inorganic matter insoluble	.00
Total	100.00

When finished, this section presented a smooth, firm surface, but when inspected it was found that a large strip had raveled for nearly the entire width of the road at station 17+30. This place was immediately repaired by first removing all the old material down to the foundation. The edges of the cut were painted with bitumen, and clean stone varying from 1 to 2 inches in size was added and tamped flush with the surface. After this the patch was finished

[1] Short semisolid; contains small amount of water.

by the penetration method, with about 2 gallons to the square yard, including the seal coat. Eight square yards of new material were thus added at a cost of 1.09 cents per square yard for the entire section.

Experiment No. 26, Section No. 28.—Refined Asphaltic Preparation—Penetration Method.

The section treated in this experiment is 51 feet long, beginning at station 21+49. The first experiment with this material was started in 1910, but the work was interrupted by bad weather, as stated in Circular No. 94 under experiment No. 16. The foundation was laid in 1910, but owning to heavy traffic during the winter it had to be spiked up, so that the wearing course might "key" with the foundation. The wearing course of stone, which ranged in sizes from 1 to 2 inches, was laid about 4 inches deep when loose and rolled until firm.

The binder was heated to between 250° and 300° F. and then drawn off in coal scuttles fitted with a strip of metal riveted across their spouts, so as to give an opening 4½ inches across and ½ inch wide. The hot binder was poured upon the prepared road surface at the rate of approximately ¾ gallon per square yard, after which the surface was given a light coat of screenings from ½ to ¾ inch in size and well rolled. The surplus screenings were then swept off with rattan hand brooms and a second application of the binder to the amount of ¾ gallon per square yard was applied. Screenings were then applied in sufficient quantity to fill all surface voids and take up the excess bitumen, after which the surface was rolled until solid.

Experiment No. 27, Section No. 30.—Refined Coal Tar—Penetration Method.

The section treated in this experiment was 110 feet long, extending from station 25 to the intersection of Central Avenue, and had an area of 225 square yards, including intersections. The wearing course of stone was laid in the same manner as in the preceding experiment. The tar was heated to from 250° to 300° F. and poured upon the prepared road surface at the rate of approximately 1½ gallons per square yard.

The surface was given a light coat of from ½ to ¾ inch screenings and rolled. The surplus screenings were then swept from the surface with rattan hand brooms and a seal coat was applied at the rate of approximately ½ gallon per square yard. Screenings were then applied in sufficient quantity to fill all surface voids and take up the surplus tar, after which the surface was rolled until firm.

The characteristics of the tar used in this experiment were as follows:

TABLE 22.—*Refined coal tar*[1] *used in experiment No. 27.*

Specific gravity 25°/25° C		1.267
Float test at 50° C. (time)		2′ 16″
Per cent of free carbon (insoluble in CS_2)		26.09
Distillation:	Per cent by volume.	Per cent by weight.
Water	0.0	0.0
First light oils to 110° C	.0	.0
Second light oils 110°–170° C	.7	.4
Heavy oils 170°–270° C	11.2	9.2
Heavy oils 270°–315° C	6.9	5.9
Pitch residue	81.2	84.5
Total	100.0	100.0

When inspected in October this section presented a uniformly smooth, well-bonded surface.

[1] Very viscous, sticky.

TABLE 23.—*Materials and cost data of experiments at Ithaca, N. Y.*

MIXING METHOD.

Experiment No.	Description.					Quantity of materials.						Cost data (cents per square yard).													Total cost.			
	Section No.	Binding materials.	Course.	Length of section (feet).	Area of section (square yards).	No. 2 stone (cubic yards per square yard).	Screenings (cubic yards per square yard).	Mixed stone (cubic yards per square yard).	Binder in mixture (gallons per square yard).	Binder used in paint coat (gallons per square yard).	Screenings used on stone shoulders (cubic yards per square yard).	No. 2 stone at siding.	Stone used in mixture at siding.	Screenings at siding.	Binder.	Hauling mixture.	Preparing and laying mixture.	Heating and applying paint coat.	Hauling and laying stone and screenings.	Rolling.	Freight on binder.	Fine grading.	Hauling binder.	Miscellaneous.	Cents (per square yard).	Entire section.	Foundation and wearing surface—basis of wearing surface (cents per square yard).	Entire section—foundation and bearing surface.
24	29	Oil-asphalt..	Foundation........	300	667	0.066	.....	.....	.....	.....	0.004	9.97	.....	0.60	.....	.....	.....	....	4.67	0.79	....	2.19	....	5.69	23.91	$159.48	92.23	$491.59
24	29	.....do......	Wearing surface....	300	533	.....	0.028	0.100	0.97	0.54	.....	....	15.10	4.23	13.59	3.00	12.56	2.63	.37	1.11	3.02	....	1.01	5.69	62.31	332.11		
25	25	.....do......	Foundation........	296	658	.....	.....	.....	.....	.....	[1].004	....	.....	.60	.....	.....	.....	....	.08	.53	....	1.34	....	1.00	3.55	14.36	62.17	327.01
25	25	.....do......	Wearing surface....	296	526	.....	.027	.090	.683	.494	.....	....	13.59	4.08	13.87	2.37	10.33	2.93	.52	1.24	3.55	....	1.27	5.69	59.44	312.65		

[1] 1910 foundation used.

TABLE 23.—*Materials and cost data of experiments at Ithaca, N. Y.*—Continued.

PENETRATION METHOD.

Experiment No.	Description: Section No.	Description: Binding materials.	Description: Course.	Description: Length of section (feet).	Description: Area of section (square yards).	Quantity of materials: No. 2 stone (cubic yards per square yard).	Quantity of materials: Screenings (cubic yards per square yard).	Quantity of materials: Binder, first application (gallons per square yard).	Quantity of materials: Binder, second application (gallons per square yard).	Quantity of materials: Screenings used on stone shoulders (cubic yards per square yard).	Cost data (cents per square yard): No. 2 stone at siding.	Cost data: Screenings at siding.	Cost data: Hauling and laying stone.	Cost data: Binder.	Cost data: Heating and applying (first application).	Cost data: Heating and applying (second application).	Cost data: Rolling.	Cost data: Freight on binder.	Cost data: Fine grading.	Cost data: Hauling binder.	Cost data: Miscellaneous.	Total cost: Cents (per square yard).	Total cost: Entire section.	Total cost: Foundation and wearing surface—basis of wearing surface (cents per square yard).	Total cost: Entire section—foundation and wearing surface.
26	28	Refined asphaltic preparation.	Foundation.......	51	113	......	......	.....	.....	[1]0.004	......	0.60	0.06	......	......	......	....	.....	5.06	....	1.00	6.72	$7.59	67.63	$60.87
26	28	.....do.............	Wearing surface...	51	90	0.117	0.028	0.83	0.75	......	17.67	4.23	1.90	18.17	2.73	2.46	2.59	3.76	......	....	5.69	59.20	53.28		
27	30	Refined coal-tar...	Foundation.......	110	262	.111	......	.....	.....	.004	16.76	.60	5.56	......	......	......	.76	.....	1.04	....	5.69	30.41	79.67	95.00	213.77
27	30	.....do.............	Wearing surface...	110	225	.097	.035	1.15	.73	......	14.65	5.30	5.61	17.86	2.28	1.44	2.22	3.76	.....	0.79	5.69	59.60	134.10		

[1] 1910 foundation used.

SUPPLEMENTARY REPORT OF EXPERIMENTS MADE AT ITHACA, N. Y., 1909 AND 1910.

TAR, OIL, NATURAL AND OIL-ASPHALT PREPARATIONS, ROCK ASPHALT, BRICK, CEMENT, AND SLAG.

A full report of these experiments is to be found in Circulars Nos. 92 and 94 of this office and a report of an inspection made November 2, 1910, of the sections then completed is also included. The following is the report of repairs made during 1911 and of an inspection on October 27, 1911. This inspection was made during a fairly heavy rain and continued on October 28, which was a clear, cold day.

Experiment No. 1.—Refined Coal Tar—Penetration Method.

No repairs have been required on this section and, when last inspected, it presented a uniformly smooth, hard, and well-bonded surface.

Experiment No. 2.—Refined Coal Tar—Mixing Method.

The only repair necessary to this section during the summer of 1911 was a small patch about 3 square feet in area at station 3 + 02. The cost of this repairing was 0.05 cent per square yard for the entire section. During the summer this section was exposed to rather severe conditions, owing to the construction of a new building along a portion of its length. At the time of inspection the greater part of it was covered with mud. The road surface in general, however, still seemed to be hard and well bonded, and the only defects noted were a few small cup-like depressions.

Experiment No. 3.—Artificial Oil-Asphalt—Mixing Method.

As noted in Circular No. 94, the grade of this section was low where it adjoined the brick section. This defect was remedied during the summer of 1911. The heated stone and bitumen were mixed exactly as for the original construction and the grade was brought up by filling in with this material; but, since this should have been done at the time of construction, the cost of making the change was not included as an item of repair. When last inspected, the surface remained in excellent condition, although considerable mud had been tracked on it from an intersecting road. The only defect noted was a small cup-like depression at station 9 + 75.

Experiment No. 4.—Artificial Oil-Asphalt—Mixing Method.

The greater part of this section showed a smooth, resilient surface-like sheet-asphalt. Throughout the last 75 feet, approaching the ash-cement-concrete section, there were occasional spots where coarse stone showed, but these had no tendency to ravel.

Experiment No. 5.—Refined Semiasphaltic Oils.—Penetration Method.

This section, while in good condition, was not as homogeneous as some of the others. Spots of coarse stone were showing in a number of places, but there was no evidence of raveling. The surface was somewhat soft and traffic had developed a small ridge on the north side of the road about the middle of the section.

Experiment No. 6.—Semisolid Refined Semiasphaltic Oil—Penetration Method.

In general this section showed a smooth, well-bonded surface resembling sheet-asphalt. Two small depressions were noted about 15 feet from the joint of the rock-asphalt section.

Experiment No. 7.—Refined Water-Gas Tar—Penetration Method.

This section presented an excellent appearance and had a smooth, hard, well-bonded surface. On that portion where an excess of binder had been used a thin film of smooth, hard bitumen covered the surface and an accumulation of mud and leaves had made it quite slippery. To remedy this difficulty, the surface was first scraped clear with hoe and shovel, after which a thin layer of limestone screenings was spread over it.

The cost of this work was 0.428 cent per square yard for the entire section.

Experiment No. 8.—Refined Semiasphaltic Oil—Penetration Method.

This section had bled considerably during the summer and surplus bitumen had flowed toward the south side of the road. The surface was softer than any of the other bituminous sections and was marked by the calks of horses' shoes. Toward the east end of the section coarse stone was showing, but the surface throughout was in very fair condition.

Experiment No. 9.—Refined Water-Gas Tar and Slag.—Penetration Method.

This section continued to be in very good condition, and the surface was firm and smooth. During the summer it was found necessary to put a small patch of about 1 square foot in this section at station 28+4. The cost of this work was 0.02 cent per square yard for the entire section.

Experiment No. 10.—Kentucky Rock Asphalt.

The general appearance of this section continues about the same as when the last inspection was made. A number of small shallow cup-like depressions were observed in the eastern half, but they are not of sufficient importance to need attention at present.

Experiment No. 11.—Open-Hearth Slag—Lime.

This section was originally constructed of open-hearth slag with slag screenings and unslaked lime for a binder. The section remained in fairly good condition throughout 1910, but after a prolonged dry spell during the early summer of 1911 the entire surface began to ravel badly. It was therefore spiked up with a roller, harrowed with a spring-tooth harrow and then shaped by hand with a potato hook and shovel. Nine cubic yards of clay were spread over the surface and thoroughly harrowed into the slag, after which the surface was rolled. Over this rolled surface there were spread 5 cubic yards of slag screenings and 1 cubic yard of limestone screenings, after which the surface was thoroughly wet and rolled.

When inspected in October, considerable mud had formed, because the clay had come to the surface. Three cubic yards of stone chips were, therefore, spread over the surface to take up this excess of clay.

The total annual cost for repairs to this section was 8.6 cents per square yard for the entire section.

Experiment No. 12.—Cement Concrete—Bituminous Surfaced.

The concrete in these sections appeared to be in good condition and no cracks were observed. The surface, however, was rather rough, and for more than the width of a wagon down the middle of the road the bituminous surfacings had practically all worn off. A thin mat of the bituminous material was observed in places along the sides of the road throughout all the concrete sections, but there was nothing to indicate that one binder had given any better results than another.

Experiment No. 13.—Ash-Cement Concrete.

This section remains in excellent condition and has a much smoother surface than the other concrete experiments. The bituminous surfacing is practically all gone from the middle of the road, but is still evident along the sides in a thin mat which can be easily stripped off.

Experiment No. 14.—Brick.

It has unfortunately become necessary to cut out a large area for the entire width of the section at about station 7 + 50, owing to a relocation of the car line which now crosses the section at this point. It is now likely that the entire brick section will be removed, owing to the relocation of the north end of East Avenue and the consequent lowering of the grade of Forest Home Drive at this point. The portions of this experiment which had not been disturbed were still in excellent condition.

Experiment No. 15.—Oil-Asphalt—Penetration Method.

In July, 1911, raveled spots were found at the following locations in this section: Station 1 + 82, 2½ square yards; station 2 + 26, 4 square feet; and station 2 + 34, 3 square feet. These places were repaired by removing the old material down to the foundation course, by a clean, straight cut. The edges were thoroughly cleaned and painted with bitumen, and the hole was then filled flush with No. 2 stone. After thoroughly tamping, bitumen and screenings were applied and this application was followed with a hot tamper. The patch was finished by the application of a seal coat and more screenings.

The cost of these repairs was 0.44 cent per square yard for the entire section. When last inspected in October, the general appearance of this section was good, although the surface was not very uniform. One small spot at station 0 + 75 showed signs of raveling and will probably have to be repaired this spring.

Experiment No. 16.—Refined Asphaltic Preparation—Penetration Method.

This experiment was laid in two sections, Nos. 26 and 27, the former of which had a seal coat, while the latter did not.

Section No. 26 includes the intersection of East and South Avenues. Owing to a leaky water pipe at this point, it became necessary to excavate at several places in the spring of 1911. This necessitated considerable repairing of the wearing surface along the east side of East Avenue and the south side of the intersection. Repairs were made in exactly the same manner as described under experiment No. 15. Since these repairs were not caused by any defects in the wearing surface, their cost is not included in the cost of maintenance of this section.

When inspected in October, the general appearance of the surface of both sections was very good, with the exception of a couple of ruts about 2 inches deep in section 27, upon which no seat coat of bitumen had been applied. These were due to the heavy hauling of coal on narrow tires along South Avenue to the power station. Considerable mud had been tracked on the surface from the upper portion of South Avenue, which is unimproved.

Experiment No. 17.—Oil-Asphalt—Mixing Method.

By July, 1911, several large raveled places had developed and patching became necessary at the following places: 3½ square yards at station 4 + 64; 4 square yards at station 5 + 36; and 1 square yard at station 5 + 6. The loose material was dug out and a patch was made in the same manner as described under the preceding experiment. When inspected in October, this section was found

to be in fairly good condition, but the surface was somewhat wavy and there were a number of small depressions scattered over it in which stone appeared to be beginning to ravel. Further repairs will probably be necessary in the spring.

The cost of these repairs amounted to 1.17 cents per square yard for the entire section.

Experiment No. 18.—Semisolid Refined Semiasphaltic Oil—Mixing Method.

When last inspected, the appearance of the surface of this section demonstrated the value of a seal coat. That portion to which such a coat had been applied was generally good and presented a smooth surface much resembling sheet-asphalt. The remainder of the section on which no seal coat was applied was fairly well bonded, but rather rough and uneven. Several open spots at about the middle of this part showed signs of beginning to ravel.

Experiment No. 19 A and B.—Refined Water-Gas Tar—Mixing Method.

The general character of this section was rough and unsatisfactory. The portion designated as section No. 22, to which a paint coat had been applied, showed raveled spots at the beginning of the section and at about 15 feet from the beginning, and was quite badly raveled for a large area at the intersection of a cross road. This was due to the mud tracked on from the cross road and from the impact of traffic coming over the gutter. About 5 square yards of new surfacing was put in here at a cost of 0.8 cent per square yard for the section.

The remainder of the experiment constituted section No. 23, to which tarred chips had been applied, instead of a paint coat. It showed an area of about 2 square yards which was beginning to ravel on the east side of the road at the beginning of the section. Strips appeared across the road at 3 feet and about 100 feet from the end of the section in which the material was evidently becoming loose and it is probable that considerable repair will be required on this section this spring.

Experiment No. 20.—Oil-asphalt—Mixing Method.

Owing to the fact that the binder used in the construction of this section was harder and more brittle than it should have been, the surface rapidly disintegrated and in July, 1911, it became necessary to resurface it entirely. This work was performed as experiment No. 25 and is described in detail in the earlier portion of this circular under experiments at Ithaca, N. Y.

Experiment No. 21.—Oil-asphalt—Prepared Filler Method.

In July, 1911, it was found necessary to repair a few raveled places as follows: $1\frac{1}{2}$ square feet at station 3+5; 1 square foot at station 3+12; 1 square foot at station 3+25; and 4 square feet at station 3+44. The work was done in exactly the same manner as described under experiment No. 15 at a cost of 2.66 cents per square yard for the entire section.

When inspected in October, the surface presented a generally good appearance, excepting for a small depression showing coarse stone at about the middle of the section.

Experiment No. 22.—Oil-Asphalt—Prepared Filler Method.

No repairs were required on this section and, when last inspected, it presented a good appearance and showed practically no difference from section 17 described in the previous experiment. A small loose spot was noted at the beginning of the section in the middle of the road.

Experiment No. 23.—Asphalt Block.

While the general appearance of this section was impaired by a heavy coat of mud which had been tracked on it, the underlying surface appeared to be smooth and in excellent condition.

SUPPLEMENTARY REPORT OF EXPERIMENTS MADE AT NEW YORK, N. Y., RIDGEWOOD, N. J., AND WASHINGTON, D. C., 1910.

OIL-CEMENT CONCRETE.

The original report of these experiments, including the report of an inspection made January 21, 1911, is to be found in Circular 94. The following additional information was gathered from an inspection made December 18, 1911.

Experiments at New York, N. Y.

The surface is worn, at every joint separating the various days' work, into a furrow from 6 to 12 inches wide in the center of the road tapering to nothing at from 8 to 10 feet from the center of the road, and from 2 to 3 inches deep. These furrows are located at approximately the following stations: 0+58, 1+20, 1+80, 2+12, 2+40, 2+75, 3+20, and 3+90. In general the surface from station 0+00 to station 3+00 is in very fair condition, with the exceptions noted above, and 6 or 8 cup-shaped depressions from 8 to 15 inches in diameter and from 1 inch to $1\frac{1}{2}$ inches in depth.

From station 3+00 to station 3+50 the entire surface is badly worn—particularly in the center of the road—and in appearance and resistance to a knife appears but little better than a macadam road.

From station 3 + 50 onward the road surface is in fair condition, except at station 3 + 90, where there is a hole 3 feet in diameter and from 2 to 3 inches deep. A joint apparently was the initial cause of failure at this point.

The cut across the road at station 2 + 30 is still filled with the refuse of the cut.

Experiments at Ridgewood, N. J.

The floors of the two bridges are in excellent condition and no worn depression is anywhere noticeable. In the middle of the roadway the wear is on the concrete, but a strip from 3 to 4 feet wide on each side of the center is covered with about an inch of dirt. At the ends of the bridges the edges of the concrete are rounded by wear, but not in an amount sufficient to be detrimental to the floor.

Experiments at Washington, D. C.

The general appearance of most of these sections, when inspected in March, 1912, had been marred by a number of openings in the surface. There are in all 16 of these places, 14 of which have an area of approximately a square yard each and are distributed along the south side of the roadway, while two larger ones have evidently been made for manholes and connections in sections No. 2 and No. 5. All of these holes have been "back-filled" with loose material and now exist as slight depressions.

The general character of the undisturbed surfaces was good throughout, with the exception of a worn depression about 2 square feet in area on the south side of section No. 2 at the middle of the section. Section No. 7, which was the first to be constructed, appeared to be a little rougher and more uneven than the others, but further than this there were no apparent differences between any of the sections.

SUPPLEMENTARY REPORT OF EXPERIMENT MADE AT BOISE, IDAHO, 1910.

OIL-GRAVEL-MACADAM.

The original report of this experiment is given in Circular No. 94, and the following is the report of an inspection made in January, 1912:

As noted in the original report, the experimental section on which data were kept was laid on a subgrade of dust, and the shoulders were nothing more than dust heaps. Most of the defects up to date are evidently attributable to this. The traffic is heavy teaming and automobiling, and the shoulders have become deeply rutted. Occasional depressions, one or two to every 50 feet, are noticeable throughout the section, but the bituminous bond is still excellent, and there is no tendency to ravel. Considerable mud has been tracked on

from intersecting roads, and this had frozen and covered the surface to the depth of an inch in places, thereby impairing the general appearance. There have been no repairs or systematic maintenance, other than occasionally cleaning the gutters, since the road was completed.

SUPPLEMENTARY REPORT OF EXPERIMENT MADE AT AMES, IOWA, 1910.

OIL-ASPHALT-GRAVEL.

The original report of this experiment is to be found in Circular No. 94. The following is the report of an inspection made November 21, 1911:

The surface is uniform throughout, excepting for a few slight breaks on the south side, about 3 feet from the curb, and these occurred during construction. About an inch of mud has been carried on from an adjoining road, which probably accounts for the fact that the section is somewhat dusty in summer. The traffic is heavy, considering that the section is on a college campus, and there is quite a large proportion of automobile traffic.

The section has been dragged a number of times in conjunction with other roads on the campus, but nothing has been spent or required for maintenance.

SUPPLEMENTARY REPORT OF EXPERIMENTS MADE AT KNOXVILLE, TENN., 1910.

TAR AND OIL PREPARATIONS.

The original report of these experiments is to be found in Circular No. 94, and the following is the report of an inspection made November 22, 1911:

All of the sections showed a firm, well-bonded surface. Most of the seal coat had worn off in experiment No. 1 and the surface presented more of a mosaic appearance than that of section No. 2. The sections constructed in experiments Nos. 1 and 2 with a refined coal-tar and refined tar preparation, respectively, were hard and smooth and could not be dug into with a knife. They both gave a more metallic ring under horses' hoofs than section No. 3, on which an oil-asphalt was used. This latter section had the appearance of sheet-asphalt, and the material was still soft and malleable when dug out with a knife. Two depressions were noted in this section, one about 2 feet in diameter at the northeast corner of the intersection with Lake Street and another on the same side of the road at the east end of the section. The surface was, however, intact throughout and the depressions were evidently due to slight settlement.

SUPPLEMENTARY REPORT OF EXPERIMENTS MADE AT YOUNGSTOWN, OHIO, 1909.

SLAG, SLAG AND LIME, SLAG AND WASTE SULPHITE LIQUOR PREPARATION, AND SLAG AND TAR.

The original report of these experiments is to be found in Circular No. 92, and the report of an inspection made January 27, 1911, appears in Circular No. 94. The inspection from which the following information was gathered was made December 10, 1911, shortly after a thin covering of snow had melted away.

Experiments Nos. 1, 2, and 3.—Blast-Furnace Slag.

An inspection of these three sections showed comparatively little difference between them. Section No. 3 appeared to be a little better bonded than the other two, but they all presented a smooth surface in the wheel tracks and a rough, rather loosened, surface in the middle of the road where horses had traveled. Section No. 2 presented the least desirable appearance in the middle of the road, owing to the fact that more of the larger-sized pieces of slag were loose and exposed. An engineer who has carefully watched the road during the entire year has reported to the office that it becomes rather loose during the spring thaw, after which it packs down to a smooth surface. There is no annoyance from dust during the summer on any of the sections.

Experiment No. 4.—Blast-furnace Slag.—Open-Hearth Slag Screenings.

This section continues about the same as when the last report was made, and presents a hard, well-bonded surface. Its general character is superior to any of the others, excepting the one treated with tar. Some slight unevenness has been caused for a distance of about 100 feet from the north end of the section, and is evidently due to a settlement in the fill over which the section was laid.

Experiment No. 5.—Blast-Furnace Slag Screenings and Lime.

This section had the same general appearance as the adjoining section described under experiment No. 1. The surface was smooth in the wheel tracks, but rough and inclined to ravel where horses had traveled.

Experiment No. 6.—Blast-Furnace Slag and Waste Sulphite Liquor Preparation.

This section presented a generally good appearance and was apparently a little better bonded than the sections described under experiments Nos. 1, 2, 3, and 4.

Experiment No. 7.—Blast-Furnace Slag and Refined Coke-Oven Tar.

In general this section appeared to be in better condition than any of the other sections. While the surface was too hard to be dug with a knife at the time inspection was made, those who have watched the work during the year report that the binder still shows considerable life in summer. Several small, loose spots appear across the road at about 80 feet and 100 feet from the north end of the section at the point where the surface extends over a fill, and there is a general slight settlement from this point across the west side of the bridge over which the section passes.

SUPPLEMENTARY REPORT OF EXPERIMENTS MADE AT NEWTON, MASS., 1908.

ASPHALTIC PREPARATIONS, TAR PREPARATIONS, RESIDUAL OIL AND MOLASSES-OIL-LIME.

These experiments are described in Circular No. 90 and reports of inspections have been published in Circulars No. 92 and No. 94. They were inspected again in January, 1912, and found to be in practically the same condition as when previously reported upon in Circular No. 94. Sections No. 9 and No. 10 continued to present the best appearance and were well bonded and in excellent condition. No repairs had been made on any of the sections since last inspected.

Section No. 11 on which a mixture of molasses, oil, and lime was used still presents a fairly satisfactory surface and was for the most part well bonded.

SUPPLEMENTARY REPORT OF EXPERIMENTS MADE AT GARDEN CITY, DODGE CITY, BUCKLIN, AND FORD, KANS., 1908.

SAND-CLAY.

The original report of these experiments is to be found in Circular No. 90, and reports of inspections in 1909 and 1910 appear in Circulars No. 92 and No. 94, respectively.

The following are reports of inspections made in 1911:

Experiment at Garden City.

This road was inspected December 15, 1911, and found to be in good condition, except as noted below. For a distance of from three to four hundred feet at the south end, the road is in excellent condition—very hard, smooth, free from ruts or dust, and with uniform surface and crown. At the junction of the surface with the floor of the bridge across the Arkansas River, the surfacing was broken, causing a drop of from 3 to 4 inches. Such broken places were in evidence at a few other locations over the roadway, but they were

all small in area and existed only where the material was crumbly. Otherwise the surfacing was closely bonded, free from ruts and dust, and hard, like macadam. Near the bridge and at two other places along the edge of the surfacing, it was broken from the attack of traffic.

This, however, is no fault of the material, but is due to the fact that the surfacing does not seem to be wide enough to accommodate the traffic. New material has been added during the summer months to the weakened places. The whole course has been thoroughly worked once with the road machine, and the split-log drag has been used after every rain on four different occasions. The road is in much better condition than when inspected one year ago and is giving general satisfaction.

Experiment at Dodge City.

The inspection of the sand-clay road in Dodge and Richland Townships, Kansas, was made December 14, 1911. The whole course was found to be in generally good condition. New material has been added to bring the weakened places up to their original condition and even with the surface. That portion of the work in Richland Township was recently given a thorough working with the road machine. The high places in the roadway and the elevations at the shoulders were pared off, so as to give the roadway a uniform surface and crown. The split-log drag was being used to spread a little sand over the surface, in order to overcome a slight tendency to stick and pick up on the wheels after a rain.

That portion in Dodge Township, about one-fourth of a mile in length, was slightly rutted and showed neglect of maintenance. The drag was not used at all on this section of the road. Several slight depressions were in evidence near the axis of the road, varying in depth from 1 to 3 inches, but covering only small areas. The deepest one was filled with water from a recent rain and the others were muddy. Otherwise the road was hard and fairly smooth, and gave a ringing sound from the horses' hoofs. The whole course is in much better condition than when inspected a year ago and is giving general satisfaction.

Experiment at Bucklin.

This road was inspected December 16, 1911, and the whole course was found to be in good condition. It has been recently repaired. New material was added where necessary, and the surfaced roadway was then worked over with the road machine, so as to produce a uniform surface and crown. After this a thin layer of sand from the sides was spread over the roadway. It was packing well under the traffic without developing ruts or cups, and gave promise of an

excellent road. At the junction of the surface with the floor of the bridge across the Arkansas River a drop of from 3 to 4 inches was in evidence, but it was still closely bonded. This had been caused by the pounding action of traffic and was the only place overlooked in the repair work.

Experiment at Ford.

The road was inspected December 16, 1911, and found to be in good condition, except as noted below. It had recently been repaired by the addition of new material which was not properly spread over the surface, but left uneven and wavy. It was closely bonded and practically free from ruts, dust or mud, although it had been exposed to a heavy rain a few days previous to the inspection.

SUPPLEMENTARY REPORT OF EXPERIMENT MADE AT INDEPENDENCE, KANS., 1908.

OIL-ASPHALT IN CONSTRUCTION OF EARTH-ASPHALT ROAD.

The original report of this experiment is to be found in Circular No. 90, and reports of inspections made in February, 1910, and February, 1911, are contained in Circulars Nos. 92 and 94. The following report is based on an inspection made December 13, 1911.

Although a heavy rain of $2\frac{1}{2}$ inches had fallen on the road only two days previous to the inspection, it was found to be generally in fair condition. Tonopah Street was covered with mud to a depth varying from 1 to 3 inches over that part disturbed by traffic, but the sides were practically free from mud and would bear light traffic without rutting. The entire surface on this street was sufficiently hard to sustain the traffic without developing ruts other than those in the mud which had been carried on from adjacent streets and washed down from the higher elevations.

Minnehaha Street, or the extension of Fourth Street, where the soil is decomposed shale and argillaceous sandstone, had the general appearance of an earth road in good condition. There was no mud on this portion of the work, except at the intersection of a cross street where two places holding water were noted. These were found to be only about 1 inch in depth and the material remained hard and intact. The surface was entirely free from dust or ruts caused by traffic; but two gullies, one on each side, which were first caused by the breaking of a water main, had begun to form. No new material has been added nor has anything been expended for maintenance since construction.

SUPPLEMENTARY REPORT OF AN EXPERIMENT MADE AT BOWLING GREEN, KY., 1907.

KENTUCKY ROCK ASPHALT.

The original report of this experiment is to be found in Circular No. 89, and reports of inspections are given in Circulars Nos. 90, 92, and 94. The inspection on which the following report is based was made November 23, 1911, during a cold and fairly heavy rain.

The surface still presented a good appearance, and was firm, hard, and generally smooth. The rock asphalt was so thoroughly chilled that it could not be easily dug out with a knife, but local observers informed the office engineers that it possesses considerable life in summer. The white spots of limestone mentioned in a previous circular were still in evidence, but the individual stones were firmly held in place.

Several small, shallow depressions were noted in the western half of the section, but these might have passed unnoticed in dry weather. The small cup-hole mentioned in Circular No. 94, however, is now about 1 foot in diameter and is to be repaired.

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Issued June 30, 1913.

U. S. DEPARTMENT OF AGRICULTURE,

OFFICE OF PUBLIC ROADS—Circular No. 99.

LOGAN WALLER PAGE, Director.

PROGRESS REPORTS OF EXPERIMENTS IN DUST PREVENTION AND ROAD PRESERVATION, 1912.

PREPARED BY THE OFFICE OF PUBLIC ROADS.

WASHINGTON:
GOVERNMENT PRINTING OFFICE.
1913.

LETTER OF TRANSMITTAL.

U. S. DEPARTMENT OF AGRICULTURE,
OFFICE OF PUBLIC ROADS,
Washington, D. C., April 23, 1913.

SIR: I have the honor to transmit herewith a manuscript of a circular prepared by this office entitled "Progress Reports of Experiments in Dust Prevention and Road Preservation, 1912." This comprises an annual review with full data regarding the experimental field work of the office, and is the seventh of a series of such publications. I recommend that this document be issued as Circular No. 99.

Respectfully,

L. W. PAGE, *Director.*

HON. D. F. HOUSTON,
Secretary of Agriculture.

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PROGRESS REPORTS OF EXPERIMENTS IN DUST PREVENTION AND ROAD PRESERVATION, 1912.

EXPERIMENTS AT CHEVY CHASE, MD.

[Completion of 1911 project.]

OILS, TAR PREPARATION, AND NATIVE ASPHALT EMULSION.

In Circular No. 98, at the conclusion of the description of the 1911 experiments at Chevy Chase, Md., it was stated that, on the east side of Connecticut Avenue a water-bound macadam road was built from station 16 + 83 to the District line, and that it was proposed to treat this with bitumens applied as surface treatment. This work was accomplished during the summer and fall of 1912, thus completing the project from the District line to Bradley Lane. The details regarding methods pursued, materials used, and cost data were as follows. The bituminous materials for all of this work were donated, and the application was made under the personal supervision of a representative of the manufacturer.

Section No. 8.—Refined Water-Gas Tar Preparation—Surface Treatment.

The section treated in this experiment is 782 feet long, extending from station 9 + 01 to station 16 + 83 on the east side of the car tracks. It comprises 1,477 square yards of finished pavement.

The bitumen was applied as a surface treatment to a water-bound macadam surface which was constructed in December, 1911. The stone used in this macadam was identical with that used in the other test sections. Owing to continued dry weather, the surface had become slightly dusty. All loose dust and screenings were removed from the surface with horse-drawn rattan-broom street sweepers, and the wearing course of stone was everywhere exposed.

The material was applied cold from an automobile distributor, which was supplied by the manufacturers of the product. The bitumen was delivered in drums and the distributor was equipped with a pump for loading from drums. One application of 0.54 gallon per square yard was made and after it had been exposed to the sun for three hours limestone chips from 1 inch to ½ inch in size were spread over the surface at the rate of 0.014 cubic yard per square yard. The road was then opened to traffic. The application was made on August 24, 1912, and the day was clear and warm.

In the compilation of the cost data no charge was made for the use of the distributor. The characteristics of the bituminous material used in this experiment are given in the following table:

TABLE 1.—*Analysis of refined water-gas tar preparation used on section No. 8.*

Specific gravity 25°/25° C		1.113
Viscosity, Engler, 50° C., 50 c. c. specific		15.5
Per cent of free carbon		3.04
Distillation:	Per cent by volume.	Per cent by weight.
Water	0.0	0.0
First light oils to 110° C	.0	.0
Second light oils 110–170° C	[1] 1.0	.6
Heavy oils 170–270° C	[1] 29.3	24.8
Heavy oils 270–315° C	[1] 10.9	9.7
Pitch residue	[2] 58.8	64.9
Total	100.0	100.0

SECTION NO. 9.—ASPHALTIC PETROLEUM—SURFACE TREATMENT.

This section extends from station 4+98 to station 9+01 on the east side of the car tracks. It comprises 761 square yards of finished pavement. The application was made to seasoned water-bound macadam which had been thoroughly swept with a horse-drawn rattan-broom street sweeper until all dust and loose screenings were removed. The road surface was slightly moist, owing to having been lightly sprinkled after it had been cleaned on the evening before the day of the application.

The bitumen was applied cold from a street sprinkler and was allowed to lie exposed on the road surface for six hours before chips were applied. Where the bitumen flowed into depressions in the road surface, it was broomed out with hand brooms to secure as uniform distribution as possible. The application was made at the rate of 0.53 gallon per square yard. Limestone chips ranging in size from 1 inch to ½ inch were spread uniformly over the surface in such quantity that 1 cubic yard covered approximately 72 square yards. The road surface was then rolled and opened to traffic.

This section was treated on June 4, 1912. The day was clear and warm, and the bitumen had been well absorbed before the screenings were applied.

The following table shows the characteristics of the bituminous material used:

[1] Clear.

[2] Sticky, semisolid. This material contained a small percentage of oil asphalt. A 350–375° C. fraction showed 7.5 per cent insoluble in dimethyl sulphate.

TABLE 2.—*Analysis of asphaltic petroleum*[1] *used on section No. 9.*

Specific gravity 25°/25° C	0.949
Flash point °C	37
Burning point °C	68
Viscosity, Engler, 25° C., 50 c. c. specific	118
Per cent of loss at 105° C., 5 hours (20 grams)	16.71
Float test of residue (50° C.) (time)	32″
Per cent of loss at 163° C., 5 hours (20 grams)	27.10
Float test of residue (50° C.) (time)	1′ 40″
Per cent of total bitumen insoluble in 86° B. naphtha	9.10
Per cent of fixed carbon	4.91
Per cent soluble in CS_2 (total bitumen)	99.88
Per cent of organic matter insoluble	.08
Per cent of inorganic matter insoluble	.04
Total	100.00

SECTION NO. 10.—RESIDUAL PETROLEUM—SURFACE TREATMENT.

This section extends from station 0 + 16 to station 4 + 98 on the east side of the car tracks and comprises a treated area of 1,013 square yards. The surface of the macadam road was prepared by sweeping with a horse-drawn steel-broom sweeper until practically all the dust within an inch of the surface had been removed, and many of the surface stones were loosened or dislodged. The oil was handled with difficulty, owing to cold weather and to the fact that it contained a small percentage of water. It was heated in a 4-barrel heating kettle and, when sufficiently fluid to be applied, was transferred to a 450-gallon tank wagon. Application was made by means of a special form of distributor attached as a trailer to the tank wagon. The oil fed by gravity to a rotary gasoline pump on the trailer and was forced through the distributor nozzles under about 60 pounds' pressure. These nozzles were constructed so that the stream of oil under pressure struck upon the apex of a grooved cone. The spray of oil was thus broken into the form of a hollow cone, having a diameter of about 12 inches at its intersection with the road surface. There were eight of these nozzles, spaced at intervals of 12 inches on a horizontal pipe, so that an 8-foot strip could be covered on each trip. The application was immediately covered with screenings, and the surface was rolled as soon as the entire section was completed. The tank and distributor were first drawn by the roller, but it was later found more convenient to use teams.

[1] Fairly thin fluid, with strong naphtha odor.

This work was done in cold weather, between November 20 and November 22. The fact that the heating plant was inadequate, and that the oil was a very viscous product, some of which contained water, resulted in higher costs than should have prevailed for this experiment. No charge was made for the tank and distributor, which were furnished by the demonstrator.

The characteristics of the oil used in this experiment are given in the following table:

TABLE 3.—*Analysis of semiasphaltic residual petroleum*[1] *used on section No. 10.*

Specific gravity 25°/25° C	0.976
Viscosity, Engler, 100° C., 100 c. c. specific	13.1
Float test at 32° C. (time)	3′ 25″
Per cent of loss at 163° C., 5 hours (20 grams)	.13
Float test of residue (32° C.) (time)	3′ 49″
Per cent of total bitumen insoluble in 86° B. naphtha	9.93
Per cent of fixed carbon	7.67
Per cent soluble in CS_2 (total bitumen)	99.74
Per cent of organic matter insoluble	.23
Per cent of inorganic matter insoluble	.03
Total	100.00

SUMMARY OF EXPERIMENTS IN SURFACE TREATMENT.

When inspected in February, 1913, it was found, on the section where refined water-gas tar preparation was used, that the entire bituminous surface had worn away, but that the binder had worked down into the interstices of the stone and was still effective as such. The surface has a mosaic appearance throughout. In one or two places, in the heavily traveled portion of the road only, has this surface broken through, causing a small muddy area in wet weather. An additional surface treatment will be required during the coming season.

On the section where asphaltic oil was used, the surface is still quite generally coated with the bitumen. At several places where traffic is concentrated, the bitumen has worn through and at the time of rains becomes slightly muddy. A surface treatment will be required to carry this section through the coming season.

The heavy, semiasphaltic oil surfacing had, of course, been on only a short time, but it was apparent that more screenings would be required with the advent of warm weather.

In the preparation of the cost data, the same unit prices prevailed as were operative during the earlier period of this project.

[1] Viscous, sticky fluid.

TABLE 4.—*Materials and cost data for experiments in surface treatment at Chevy Chase, Md.*

Section No.	Materials.	Area of section.	Quantity of materials per square yard.		Cost per square yard.									Entire cost of section.
			Bitumen.	Screenings.	Bitumen.	Screenings on work.	Cleaning surface.	Heating and handling bitumen.	Loading distributor.	Applying bitumen.	Spreading screenings.	Rolling.	Total of items.	
		Sq. yds.	*Gal.*	*Cu. yd.*	*Cts.*	*Cts.*	*Cts.*	*Cts.*	*Cts.*	*Cts.*	*Cts.*	*Cts.*	*Cts.*	
8	Refined water-gas tar preparation	1,477	0.54	0.014	2.70	3.00	0.81	......	[1]	[1]	0.50	.....	7.01	$103.54
9	Asphaltic petroleum	761	.53	.014	3.71	3.00	.81	......	0.48	0.63	.47	0.33	9.43	71.76
10	Residual petroleum	1,013	.79	.018	4.15	3.82	.73	[2] 1.20	.....	.50	.83	.50	11.73	118.82

[1] Automobile distributor used; no cost assigned for charging or distributing.
[2] Includes loading distributor.

SECTION NO. 11.—NATIVE ASPHALT EMULSION—MACADAM RESURFACING.

This section extends from the District line at station $-1+85$ to station $0+16$ and has a total area of 388 square yards. It was planned to make it a part of the previous section and it was swept for this purpose, but, owing to a lack of oil, the work could not be completed. The surface was therefore left loose in places and generally rough. It was spiked up with the road roller and harrowed in order to shake down any fine material and leave only the large stones in the surface. Additional new limestone was spread over the surface in order to provide a layer of loose stone about 3 inches thick. This layer was composed of fragments ranging in size from 2½ inches to 1 inch in their longest dimension.

A rather wet mortar was then prepared by mixing fine trap screenings with the emulsion, the characteristics of which are shown in Table 6, using approximately 10½ gallons of emulsion to 4 cubic feet of screenings. The mixing was done in a revolving type of concrete mixer located at one end of the work, and the mortar was carried in wheelbarrows, dumped directly on the loose stone, and spread to an even surface with rakes. It was spread to a thickness of about 2½ inches above the finished grade of the road and, as soon as it had begun to dry out, as evidenced by a change of color from brown to black, trap screenings were spread over the surface, and a 10-ton road roller was used to force the mortar into the voids between the stone. The mortar picked up in clods at first, but these were shoveled back into place and the rolling was continued until only a thin layer of material remained above the surface stone.

The work on this section was done between December 9 and December 16, and was interrupted by freezing weather and the necessity for drying about one-half of the screenings used. These facts account for a cost higher than it should be. The surface should have been finished by thoroughly sweeping it after it had completely dried out, and then applying a flush coat of emulsion followed by screenings, but owing to adverse conditions, this part of the work was postponed until spring.

The following tables show the character of the trap screenings and the analysis of the emulsion used:

TABLE 5.—*Mechanical analysis of trap-rock screenings.*

Passing $\frac{1}{2}$-inch screen, retained on $\frac{1}{4}$-inch screen	per cent	12.5
Passing $\frac{1}{4}$-inch screen, retained on $\frac{1}{8}$-inch screen	do	22.8
Passing $\frac{1}{8}$-inch screen, retained on 10-mesh screen	do	12.5
Passing 10-mesh screen, retained on 20-mesh screen	do	16.3
Passing 20-mesh screen, retained on 30-mesh screen	do	7.8
Passing 30-mesh screen, retained on 50-mesh screen	do	7.6
Passing 50-mesh screen, retained on 80-mesh screen	do	5.6
Passing 80-mesh screen, retained on 100-mesh screen	do	3.2
Passing 100-mesh screen, retained on 200-mesh screen	do	6.2
Passing 200-mesh screen	do	5.5
Total	do	100.0

TABLE 6.—*Analysis of native asphalt emulsion used in section No. 11.*

Specific gravity 25°/25°C.		1.038
Per cent of loss at 105°C. 5 hours (20 grams)		52.54
Penetration of residue (100 grams, 5 seconds, 25°C.) [mm]		19.5
Per cent of loss at 163°C. (additional to above)		3.35
Penetration of residue (as above) [mm]		7.2
Approximate composition:		
Water	per cent	49.50
Ammonium (NH_3)	do	.35
Fatty and resin acids	do	9.45
Bitumen	do	36.30
Organic matter insoluble in CS_2	do	1.10
Inorganic matter	do	3.30
Total		100.00

In the cost data which follow no charge for moving or rent of the concrete mixer is made; it was furnished by the manufacturer donating the material. The same labor costs prevailed as in the previously described experiments, and the trap screenings were figured at $2.40 per cubic yard on the work

TABLE 7—*Materials and cost data for resurfacing with native asphalt emulsion at Chevy Chase, Md.*

Total area resurfaced, square yards	377
Materials per square yard:	
Emulsion, gallons	3.32
No. 1 stone, cubic yards	.019
Screenings, cubic yards	.045
Cost per square yard (cents):	
Spiking and picking old surface	1.07
Harrowing	.50
No. 1 stone	.47
Spreading No. 1 stone	4.64
Screenings	10.82
Drying screenings	4.38
Emulsion	43.10
Mixing and laying mortar	10.90
Rolling	2.65
Coal	1.06
Watchman	1.92
Total	81.51

EXPERIMENTS AT CHEVY CHASE, MD., 1912.

BITUMINOUS CONCRETE, CEMENT CONCRETE, OIL-CEMENT CONCRETE.

The 1912 experiments at Chevy Chase, Md., form a continuation of the experimental sections constructed during 1911. They were conducted upon a section of Connecticut Avenue, 6,195 feet in length, beginning at Bradley Lane, and extending north to the loop of the Capital Traction Co. tracks at Chevy Chase Lake.

The work was begun on September 9, 1912, and was continued until December 13, 1912, when, owing to unfavorable weather conditions, it was discontinued. A length of 4,561 feet was partially completed. This will be completed and the remaining sections constructed in the spring of 1913.

The section of Connecticut Avenue selected for the experiments is on the west side of the tracks of the Capital Traction Co. and was formerly an 8-inch water-bound limestone macadam road. A cobble gutter was laid along a part of its length on the west side, but was provided with no outlet in practically the entire length of the section. When the experimental work was begun, the road had worn into a series of large depressions and was in an intolerably dusty condition.

This old surface was spiked up with a steam roller and broken with a plow and a scarifier, and the excavation and shaping of the subgrade were completed by hand labor. French drains 3 feet deep

along the car track and 2 feet deep under the gutter supplied subdrainage where it was required, and the stone removed from the old road surface was "shaken out" and used in the drain trench. A concrete gutter of the "barrel" type, 3 feet wide and 4 inches deep, was laid along the west side of the road, and the distance from the outside of the rail to the outside edge of the gutter was 25 feet 9 inches. The gutter, as constructed, formed a shoulder for the pavements, and consisted of a base of concrete in the proportions of 1 part by volume of Portland cement to 2 parts of sand and 4 parts of gravel, and a top course of ½ inch of mortar in the proportions of 1 part by volume of Portland cement to 2 parts of sand.

The experimental pavements were laid adjoining the gutter and on the foundation, which were prepared as described above. A single contract was awarded upon plans and specifications prepared in the Office of Public Roads for the construction of six experimental sections, as follows:

Section 1.—Bituminous concrete (Topeka specifications).
Section 2.—Bituminous concrete (District of Columbia specifications).
Section 3.—Cement concrete, surface coated with bituminous materials.
Section 4.—Oil-cement concrete.
Section 5.—Cement concrete.
Section 6.—Vitrified brick.

Sections 1 and 2 were entirely completed; section 3 was completed with the exception of applying the bituminous surfaces; sections 4 and 5 were partially completed; and section 6 was not begun.

The equipment consisted of a concrete mixer of the self-propelled rotary-distributor type, two 200-gallon heating kettles, a patented hand distributor, pouring pots, two 10-ton rollers of the 3-wheel type, a 10-ton and a 3-ton tandem roller, a scarifier, plows, and hand tools. Efficient labor was furnished and the work was done as expeditiously as possible, but considerable time was unavoidably lost by reason of unfavorable weather conditions and the delayed arrival of materials.

Experiment No. 1.—Bituminous Concrete (Topeka Specifications).

Beginning with station 0 − 15 at the south side of the intersection of Bradley Lane and Connecticut Avenue, and adjoining the experimental surfaces constructed in 1911, this section extends to station 6 + 20 and contains 1,498 square yards. The surface of bituminous concrete was laid upon a cement-concrete foundation, which was made up of 1 part by volume of Portland cement, 3 parts of sand and 7 parts of gravel. A bag of cement was considered to have a volume of 1 cubic foot. The concrete was mixed in a mechanical concrete mixer of the self-propelled rotary-distributor type. The

materials were properly proportioned in a charging device or "skip," which was then raised mechanically and the contents were dumped into the drum. The water, automatically measured in an overhead tank, was turned into the drum at the same time, and the concrete, after being partly mixed in the drum, was discharged into the rotary distributor, where the process of mixing was continued until the concrete was discharged from the end of the tube. The flow was practically continuous, and the distributor was swung across the road and the mixer moved ahead in such manner as to place the concrete upon the subgrade in approximately the position desired. It was then shoveled into place in such amount as to form when compacted a uniform layer 6 inches in thickness. The mass was compacted by tamping with concrete tampers, and the surface was then slightly indented by further striking with a rattan broom.

Before the concrete of the base had taken initial set a shoulder 6 inches wide and 2 inches deep of cement mortar, made in the proportion of 1 part of Portland cement to 2 parts of sand, was placed upon all edges of the base except those which abut against the concrete gutter.

The bituminous-concrete pavement was not laid until a month after the completion of the base. The surface of the base was then swept clean and all loose pebbles were removed. The bituminous concrete was mixed at a paving plant and hauled in wagons to the work—a distance of approximately 6 miles. It arrived upon the road at an average temperature of 280° F., and was immediately spread uniformly on the base with rakes in such quantity as to insure a thickness of 2 inches after rolling. The first rolling, which was begun immediately, was done by a 3-ton tandem roller, and this was followed with a 10-ton tandem roller. The surface was finished by sweeping a light covering of Portland cement over it.

Between station 6 + 20 and station 4 + 26 the pavement was hauled and laid during a drizzling rain and some of the bituminous concrete was in a cold and lumpy condition.

An effort to secure the proportions specified for "Topeka" pavement was made by using only crushed rock and limestone dust for an aggregate, although it was evident that it would be difficult to obtain the exact proportions without using a certain amount of sand. Owing to impending winter weather and the necessity for prosecuting the work rapidly, the specifications were less rigidly interpreted than they would otherwise have been.

From station 0 + 15 to station 3 + 19 the mixture consisted of 7.6 cubic feet of limestone screenings, 8.8 gallons of asphaltic cement, and from 50 to 70 pounds of limestone dust.

From station 3 + 19 to station 6 + 20 the mixture consisted of 8 cubic feet of trap-rock screenings, 9.3 gallons of asphaltic cement,

and 60 pounds of limestone dust. Complete analyses of both mixtures are given in the following table:

TABLE 8.—*Analyses of "Topeka" bituminous-concrete mixtures.*

	Limestone.	Trap rock.
Bitumen soluble in CS_2 (total bitumen) per cent	7.1	8.7
Mineral aggregate passing $\frac{3}{4}$-inch screen, retained on $\frac{1}{2}$-inch screen, per cent	1.8	2.0
Mineral aggregate passing $\frac{1}{2}$-inch screen, retained on $\frac{1}{4}$-inch screen, per cent	11.3	14.0
Mineral aggregate passing $\frac{1}{4}$-inch screen, retained on $\frac{1}{8}$-inch screen, per cent	20.5	13.0
Mineral aggregate passing $\frac{1}{8}$-inch screen, retained on 10-mesh screen, per cent	14.5	8.8
Mineral aggregate passing 10-mesh screen, retained on 20-mesh screen, per cent	15.8	17.0
Mineral aggregate passing 20-mesh screen, retained on 30-mesh screen, per cent	5.8	7.3
Mineral aggregate passing 30-mesh screen, retained on 40-mesh screen, per cent	3.8	4.0
Mineral aggregate passing 40-mesh screen, retained on 50-mesh screen, per cent	1.6	2.3
Mineral aggregate passing 50-mesh screen, retained on 80-mesh screen, per cent	3.3	4.4
Mineral aggregate passing 80-mesh screen, retained on 100-mesh screen per cent	1.5	1.8
Mineral aggregate passing 100-mesh screen, retained on 200-mesh screen per cent	2.9	4.6
Mineral aggregate passing 200-mesh screen do	10.1	12.1
Total do	100.0	100.0

The binder was a fluxed native asphalt having a penetration of from 6 to 6.5 millimeters at 25° C. The general characteristics of a sample are given in the following table:

TABLE 9.—*Analysis of fluxed native asphalt used in experiments No. 1 and No. 2.*

Specific gravity 25°/25° C	1.074
Melting point ° C	53.0
Penetration (25° C., 100 grams, 5 seconds) [mm.]	6.0
Per cent of loss at 163° C. (20 grams)	2.86
Penetration of residue (as above) [mm.]	2.9
Per cent of total bitumen insoluble in 86° B. naphtha	23.83
Per cent of fixed carbon	11.20
Per cent soluble in CS_2 (total bitumen)	93.56
Per cent of organic matter insoluble	1.86
Per cent of inorganic matter insoluble	4.58
Total	100.00

EXPERIMENT NO. 2.—BITUMINOUS CONCRETE (DISTRICT OF COLUMBIA SPECIFICATIONS).

This section extends from station 6+20 to station 12+50, a distance of 630 feet, and contains 1,400 square yards.

A cement-concrete base and a 2-inch by 6-inch mortar shoulder were constructed as described under experiment No. 1, and, as in that experiment, a delay of one month was experienced before the bituminous-concrete pavement was laid.

The surface of the base was swept clean prior to the application of the hot material and the latter was then spread uniformly over the base and rolled as described under experiment No. 1. The part of the section between stations 6+20 and 7+00 was laid during the rain mentioned under experiment No. 1.

The bituminous concrete was mixed at the paving plant about 6 miles from the work, to which it was hauled in wagons. From station 6+20 to station 9+04 the mixture consisted of 7.6 cubic feet of crushed limestone, 4 cubic feet of sand, 60 pounds of limestone dust, and 9.3 gallons of asphaltic cement. From station 9+04 to station 12+50 the mixture consisted of 7.6 cubic feet of crushed trap rock, 4 cubic feet of sand, 50 pounds of limestone dust, and 8.2 gallons of asphaltic cement.

The asphaltic cement was the same as that used in experiment No. 1, the analysis of which is given in table 9. The characteristics of the other materials used in experiment No. 2 are given in the following tables:

TABLE 10.—*Mechanical analysis of crushed rock used in bituminous concrete for experiment No. 2.*

		Limestone.	Trap rock.
Passing 1¼-inch screen, retained on 1-inch screen	per cent	4.3	5.8
Passing 1-inch screen, retained on ¾-inch screen	do	15.3	27.7
Passing ¾-inch screen, retained on ½-inch screen	do	34.4	38.6
Passing ½-inch screen, retained on ¼-inch screen	do	30.0	24.6
Passing ¼-inch screen, retained on ⅛-inch screen	do	10.3	2.5
Passing ⅛-inch screen, retained on 100-mesh screen	do	5.2	.4
Passing 100-mesh screen	do	.5	.4
Total	do	100.0	100.0

TABLE 11.—*Analysis of sand used in bituminous concrete for experiment No. 2.*

Passing 4-mesh screen, retained on 8-mesh screen	per cent	33.8
Passing 8-mesh screen, retained on 10-mesh screen	do	9.4
Passing 10-mesh screen, retained on 20-mesh screen	do	20.8
Passing 20-mesh screen, retained on 30-mesh screen	do	11.4
Passing 30-mesh screen, retained on 40-mesh screen	do	8.3
Passing 40-mesh screen, retained on 50-mesh screen	do	6.9
Passing 50-mesh screen, retained on 80-mesh screen	do	5.4
Passing 80-mesh screen, retained on 100-mesh screen	do	.1
Passing 100-mesh screen, retained on 200-mesh screen	do	2.2
Passing 200-mesh screen	do	1.7
Total	do	100.0

The following table shows the average analyses of material taken from carts:

TABLE 12.—*Analyses of bituminous concrete used in experiment No. 2.*

	Limestone.	Trap rock.
Bitumen soluble in CS_2 (total bitumen)....per cent..	6.7	6.7
Mineral aggregate passing 1¼-inch screen, retained on 1-inch screen, per cent....	2.1	0.0
Mineral aggregate passing 1-inch screen, retained on ¾-inch screen, per cent....	13.2	6.5
Mineral aggregate passing ¾-inch screen, retained on ½-inch screen, per cent....	16.7	15.2
Mineral aggregate passing ½-inch screen, retained on ¼-inch screen, per cent....	13.5	19.2
Mineral aggregate passing ¼-inch screen, retained on ⅛-inch screen, per cent....	12.7	13.5
Mineral aggregate passing ⅛-inch screen, retained on 10-mesh screen, per cent....	6.5	7.4
Mineral aggregate passing 10-mesh screen, retained on 20-mesh screen, per cent....	7.6	8.7
Mineral aggregate passing 20-mesh screen, retained on 30-mesh screen, per cent....	3.5	4.0
Mineral aggregate passing 30-mesh screen, retained on 40-mesh screen, per cent....	3.3	3.3
Mineral aggregate passing 40-mesh screen, retained on 50-mesh screen, per cent....	2.0	1.9
Mineral aggregate passing 50-mesh screen, retained on 80-mesh screen, per cent....	4.1	4.0
Mineral aggregate passing 80-mesh screen, retained on 100-mesh screen....per cent..	1.1	1.2
Mineral aggregate passing 100-mesh screen, retained on 200-mesh screen....per cent..	2.0	2.6
Mineral aggregate passing 200-mesh screen....do....	5.0	5.8
Total....do....	100.0	100.0

After another delay of one week, due to unfavorable weather, a fluxed native asphalt of the same general character as that used in the body of the pavement was applied as a seal coat by means of a patented hand distributor. The seal coat was immediately followed by a layer of clean stone chips, after which the surface was rolled. The average temperature at the time of application was 35° F., and the bitumen hardened immediately upon touching the surface. It was therefore impossible to effect a uniform distribution of the material.

EXPERIMENT NO. 3.—CEMENT CONCRETE—SURFACE COATED WITH BITUMINOUS MATERIALS.

This section adjoins the one just described, is 1,253 feet in length, and contains 2,837 square yards. The concrete was mixed in the mechanical batch mixer described under experiment No. 1 in the proportions of 1 part of Portland cement to 1¾ parts of sand and 3

parts of coarse aggregate. Between stations 12 + 50 and 15 + 84 and between stations 21 + 60 and 25 + 03 a gravel aggregate was used which consisted of particles of stone well graded in size between those retained on a screen having ¼-inch circular openings and those passing a screen having 1½-inch circular openings. It was also provided that not more than 75 per cent should pass and not more than 75 per cent be retained on a screen having ¾-inch circular openings. Between stations 15 + 84 and 21 + 60 a crushed limestone aggregate was used which consisted of that part of the run of the crusher which was retained on a screen having ¼-inch circular openings and which passed a screen having 1½-inch circular openings. The method of mixing was the same as that described under experiment No. 1, except that a greater quantity of water in an amount necessary to give the concrete a "quaky" consistency was added. The concrete was spread evenly over the subgrade with rakes and shovels to a depth slightly greater than the finished thickness of 6 inches, and the surface was then "struck off" by means of an especially designed "strike board." After this the surface was finished to true grade and cross section with a wooden float. The floating was done from a bridge which rested upon the side forms and the concrete gutter and could be advanced as the work progressed. Joints between the days' work were formed by placing a 3 by 6 inch plank on edge at an angle of 80° to the center line of the road. Before continuing the work of laying the concrete the plank was removed and the face of the joint was washed with a 10-per cent solution of muriatic acid, followed by water.

As soon as practicable after laying the pavement it was covered with canvas and was so protected until the concrete had thoroughly set. The canvas covers were then removed and the concrete was covered with a layer of loam or sand about 2 inches in depth, which was kept thoroughly wet for a period of eight days. The covering was allowed to remain on the pavement for a period of 15 days, after which it was removed whenever it was convenient to do so. Loam was at first used for this covering, but it was found to be difficult to remove it entirely, and sand was therefore adopted as a covering on all sections which it is planned to cover with a bituminous carpet coat. This coat was omitted from the original construction on account of cold weather, and the work will be done in the spring of 1913.

Experiment No. 4.—Oil-Cement Concrete.

This section was constructed in two parts and is not yet completed. It adjoins the former section at station 25 + 03 and extends to station 33 + 60, where it is interrupted and is continued from station 42 + 50 to station 44 + 61. The length of the part constructed is 1,068 feet and it contains 2,430 square yards.

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From station 25+03 to station 27+29 and from station 42+50 to station 44+61 a coarse aggregate of crushed limestone was used. From station 27+29 to station 33+60 the aggregate used was gravel. The character of the materials used and the method of construction were the same as described under experiment No. 3, with the exception that a light residual petroleum, having the characteristics represented in Table 13, was mixed with the concrete to the amount of 5 pints per bag of cement.

TABLE 13.—*Analysis of fluid residual petroleum used in oil-cement concrete for experiment No. 4.*

Specific gravity 25°/25° C.	0.933
Viscosity, Engler, 50° C., 100 c. c. specific	27.8
Per cent of loss at 163° C. (20 grams)	2.67
Float test of residue, 32° C. (time)	1′ 35″
Per cent of total bitumen insoluble in 86° B. naphtha	2.31
Per cent of fixed carbon	3.01
Per cent soluble in CS_2 (total bitumen)	99.90
Per cent of organic matter insoluble	.08
Per cent of inorganic matter insoluble	.02
Total	100.00

The total length of this section as planned is to be 1,350 feet. The remaining length will be constructed in the spring of 1913 and the surface of the section from station 25+03 to station 31+00 will also be given a bituminous carpet coat at that time.

EXPERIMENT NO. 5.—CEMENT CONCRETE.

This section lies between the two parts of experiment No. 4 and extends from station 33+60 to station 42+50, a distance of 890 feet. It comprises 2,011 square yards. The materials used and the method of construction were the same as described under experiment No. 3.

The remainder of this section, to a total length of 1,350 feet, will be completed in the spring of 1913. No bituminous carpet coat will be applied.

EXPERIMENT NO. 6.—VITRIFIED BRICK.

No work was done on this section. It will be constructed in the spring of 1913.

SUMMARY OF 1912 EXPERIMENTS AT CHEVY CHASE, MD.

When inspected in March, 1913, all of the surfaces were in excellent condition. Transverse contraction cracks had developed throughout the length of the gutter and at varying intervals throughout the several sections of concrete pavement. About 50 per cent of the cracks in the latter had formed at the same point as cracks which had already developed in the gutter before the pavement was laid. Pavement cracks occurred at less intervals throughout the

plain gravel and oil-cement-gravel concrete than in the sections where limestone aggregate was used, but this may possibly be due to the fact that the latter sections were laid in colder weather and were consequently less liable to contraction from a fall in temperature during the early period of hardening.

In connection with this experimental concrete roadway, an interesting set of observations is being taken on the change in length of the concrete. It is hoped that by accurately measuring the change in length of the concrete roadway, due both to temperature and to moisture, data of practical value will be obtained to permit more efficient spacing of the so-called expansion joints. In the experimental road at Chevy Chase, measurements will be taken over sections of plain concrete with gravel, limestone, and trap-rock aggregates, over sections having bituminous coatings, and over sections of oil-mixed Portland cement concrete. For this purpose brass plugs 5 inches in length and three-fourths inch in diameter are being embedded in the concrete just before the final floating and are spaced in double rows 5 feet from the sides of the road, one row with a 10-foot spacing and the other with a 50-foot spacing. The latter are for making lateral readings. The tops of the plugs are drilled with a $\frac{1}{16}$-inch hole and are protected by means of a brass collar into which a plug of putty is inserted.

Measurements are taken from plug to plug by means of a specially designed 10-foot strain gauge. This instrument, which was designed to give an accuracy of $\frac{1}{1000}$ inch in 10 feet, consists of two $\frac{1}{2}$-inch tubes, one of brass and the other of steel, inclosed in a double brass casing, with diameters of 3 inches for the outer casing and 2 inches for the inner casing. The ends of the instrument are supported by castings containing hardened steel points, and one of these castings is fitted with two micrometer heads and the other with two hardened steel plugs with flat ends. Readings are taken by resting the two points of the instrument in the $\frac{1}{16}$-inch holes drilled in the embedded brass plugs. The double tubes, one of steel and the other of brass, are used to take care of temperature changes as readings are taken at different seasons of the year. The instrument has been carefully calibrated by reading on a steel gauge bar immersed in water at a constant temperature. Steam was passed through the inner casing and readings were taken upon micrometers, and finally cold air was likewise passed until the bars had both been reduced to the same temperature, when micrometer readings were again taken. From the result of this calibration means are at hand for judging the average temperature of the tubes from their measured difference in length and a very accurate method is furnished of reducing the micrometer readings on the road to what they would be if the temperature were to remain constant.

The following approximate costs to date are given, although these will be subject to revision when the project is completed and several items of miscellaneous and overhead charges can be properly redistributed. The final tabulation of materials and cost data will therefore appear in a later report.

TABLE 14.—*Approximate cost of 1912 experiments at Chevy Chase, Md.*

UNIT COSTS.

	Cents.
Materials delivered on road:	
Cement (per barrel)	162
Sand (per ton)	110
Gravel (per ton)	136
Limestone (per ton)	155
Water furnished free from hydrants along road.	
Labor (per hour):	
Unskilled	22½
Cement finisher	50
Engineers	50
Carpenter	50
Foreman	60

APPROXIMATE COST PER SQUARE YARD.

		Cents.
Experiments Nos. 1 and 2:		
Grading and shaping		20.0
Concrete base		78.5
Bituminous concrete—		
Mix at plant	[1] 43	
Hauling from plant to road	[1] 19	
Laying	[1] 6	
		[1] 68.0
Superintendence and miscellaneous		27.0
Total		193.5
Mortar shoulder, 2 by 6 inches (per linear foot)		1.4

	Gravel aggregate.	Limestone aggregate.
Experiment No. 3:		
Preparing foundation	19.80	19.80
Concrete pavement	94.34	97.34
Protection of pavement after laying	1.55	1.55
Superintendence	14.89	14.89
Miscellaneous	11.43	11.43
Total	142.01	145.01
Experiment No. 4:		
Preparing foundation	19.80	19.80
Oil-concrete pavement	102.00	105.00
Protection of pavement after laying	1.55	1.55
Superintendence	14.72	14.72
Miscellaneous	11.43	11.43
Total	149.50	152.50

[1] Estimated.

Experiment No. 5:	Gravel aggregate.	Limestone aggregate.
Preparing foundation	19.80	19.80
Concrete pavement	94.34	97.34
Protection of pavement after laying	1.55	1.55
Superintendence	14.50	14.50
Miscellaneous	11.43	11.43
Total	141.62	144.62
Gutter (per linear foot)	60.00	60.00

EXPERIMENTS AT WASHINGTON, D. C.

TAR PREPARATION AND OILS—SURFACE TREATMENT.

The following series of experiments was conducted on the roads traversing grounds of the Department of Agriculture, Washington, D. C., for the purpose of obtaining comparative data on several well-known bituminous materials adapted to cold-surface treatment. The roads selected had been entirely resurfaced with limestone macadam in the fall of 1911 and are 16 feet in width. Although subjected to only a moderate traffic of light delivery wagons, carriages, and automobiles, the surface had worn perceptibly during the summer of 1912, and the repair of a number of small depressions was necessary before the surface treatments were applied.

In June, 1912, the entire area of these roads was treated with a molasses-lime mixture, using the same proportions as given in Circular No. 98 for the treatment of Bradley Lane. A steel sprinkler was used and the mixing was done directly in the sprinkler. The cost of the application, including repairs to the surface, was 2 cents per square yard. The treatment was followed by heavy rains covering a period of about 10 days, which washed most of the application from the surface and the roads soon became dusty.

The following experiments were conducted during the last week in October, 1912. Owing to rather cold weather during this period, all of the materials required a slight amount of heating, which would not have been necessary earlier in the season.

The road surface was in all cases thoroughly cleaned by sweeping with hand push brooms; all holes and depressions were picked out clean to a depth of 2½ or 3 inches and filled with new stone and screenings, which were "hand-tamped" into place with sufficient water to make the patch secure. The bitumens were all applied by means of a 750-gallon pressure distributor, in which the pressure was produced by means of a rotary pump operated from the driving wheel by means of a chain and sprocket. It was drawn by four horses and a pressure of from 60 to 75 pounds could be easily maintained. The oil was driven upon the road in the form of a series of fan-shaped sprays having a width of approximately 9 inches at their intersection with the surface. Eight nozzles made it possible to apply a 6-foot strip for each run of the distributor. The materials all came in 50-gallon drums or barrels which were rolled by hand up an incline of planks

and allowed to drain from the bung into the manhole of the distributor tank.

The application was covered with a layer of screened and washed river gravel, and the mechanical analyses of two grades used are shown in the following table:

TABLE 15.—*Mechanical analyses of gravels used in surface-treatment experiments.*

	Coarse, section 1.	Fine, sections 2, 3, 4.
Retained on ½-inch screen........per cent..	16.0	2.2
Retained on ¼-inch screen........do....	67.0	56.2
Retained on ⅛-inch screen........do....	16.0	27.8
Retained on 10-mesh screen........do....	.6	4.2
Passing 10-mesh screen........do....	.4	9.6
Total........do....	100.0	100.0

SECTION NO. 1.—REFINED WATER-GAS TAR PREPARATION.

This section runs parallel to Fourteenth Street and at its north end intersects section No. 2. Including the triangle at this north intersection, it has a total area of 1,318 square yards. The distribution was somewhat uneven, and it was thought best to defer spreading the gravel for a day in order to allow the tar to penetrate better and be broomed more evenly when the sun had rendered it more fluid. A heavy rain came on and the wind brought down large quantities of leaves which adhered to the sticky surface. After two days these were removed as much as was possible by raking, and the gravel was spread while the section still showed small pools of water throughout its length. Most of the gravel for the north half of the section was dried, but, when rain came on again, the drying was discontinued. The coarse gravel was used on this section, excepting for a short stretch at the south end, where the finer grade was used. After thorough rolling the section was opened to traffic.

The characteristics of the tar used in this experiment are shown in the following table:

TABLE 16.—*Analysis of refined water-gas tar* [1] *used on section No. 1.*

Specific gravity 25°/25° C........	1.126
Viscosity, Engler, 50° C., 50 c. c. specific........	29.8
Per cent of free carbon (insoluble in CS_2)........	2.43

Distillation:	Per cent by volume.	Per cent by weight.
Water........	0.0	0.0
First light oils to 110° C. (clear)........	.6	.5
Second light oils 110–170° C. (turbid)........	1.9	1.6
Heavy oils 170–270° C. (slightly turbid)........	21.4	18.8
Heavy oils 270–315° C. (clear)........	[2] 14.5	13.1
Pitch residue........	61.6	65.9
Total........	100.0	99.9

[1] Rather viscous, sticky fluid.

[2] Showed 7.5 per cent insoluble in dimethyl sulphate. A 315–350° C. fraction showed 10 per cent and a 350–375° C. fraction showed 7.5 per cent insoluble in dimethyl sulphate. The material therefore contains a small percentage of oil asphalt.

SECTION NO. 2.—ASPHALTIC PETROLEUM.

Section No. 2 connects Thirteenth and Fourteenth Streets. It is 635 feet in length and has an area of 1,129 square yards. The characteristics of the oil used are shown in the following table:

TABLE 17.—*Analysis of asphaltic petroleum*[1] *used on section No. 2.*

Specific gravity 25°/25° C	0.947
Flash point ° C	32
Burning point ° C	68
Viscosity, Engler, 25° C., 50 c. c. specific	88.1
Per cent of loss at 163° C	28.06
Float test of residue 50° C (time)[2]	1′ 45″
Per cent of total bitumen insoluble in 86° B. naphtha	8.88
Per cent of fixed carbon	4.84
Per cent soluble in CS_2 (total bitumen)	99.88
Per cent of organic matter insoluble	.08
Per cent of inorganic matter insoluble	.04
Total	100.00

The application was immediately covered with the fine gravel, but owing to a failure in the delivery of this material the gravel was spread very thin at first and more was put on during the next few days as it was received. Practically all of the gravel on this and the two sections which follow was wet when spread.

SECTION NO. 3.—RESIDUAL PETROLEUM.

Section No. 3 is an extension of section No. 2 and connects Twelfth and Thirteenth Streets. It has an area of 711 square yards. The character of oil used is shown by the following table:

TABLE 18.—*Analysis of semiasphaltic residual petroleum*[3] *used on section No. 3.*

Specific gravity 25°/25° C	0.957
Flash point ° C	167
Burning point ° C	198
Viscosity, Engler, 50° C., 50 c. c. specific	43
Per cent of loss at 163° C.[4]	7.31
Per cent of total bitumen insoluble in 86° B. naphtha	.65
Per cent of fixed carbon	1.47
Per cent soluble in CS_2 (total bitumen)	99.92
Per cent of organic matter insoluble	.05
Per cent of inorganic matter insoluble	.03
Total	100.00

[1] Thin fluid, with strong naphtha odor.
[2] Soft, with slight flow.
[3] Slightly sticky fluid.
[4] Residue too fluid for float test.

The application was immediately covered with the fine gravel and the surface was rolled the following day. The oil began to "bleed" after a few days, producing a sticky surface when the nights became cold, and small strips were picked out by automobile tires. The surface therefore received a light application of sand on three separate occasions.

SECTION NO. 4.—ASPHALTIC PETROLEUM.

Section No. 4 is parallel to Twelfth Street and runs south from section No. 3. Including the two arms of the "Y" at its north end it has a total area of 1,330 square yards. The oil was applied to such an extent as the road surface would retain, but, owing to the lower viscosity of the material, a single application could not be made as heavy as with the materials used on the previously described sections. Fine gravel was applied a few hours after the application was made and the surface was rolled the following day.

The following table gives the characteristics of the oil used:

TABLE 19.—*Analysis of asphaltic petroleum*[1] *used on section No. 4.*

Specific gravity 25°/25° C.	0.926
Flash point ° C.	27
Burning point ° C.	46
Viscosity, Engler, 25° C., 100 c. c. specific	41.5
Per cent of loss at 163 °C.	25.83
Float test of residue 50° C. (time)[2]	1′ 11″
Per cent of total bitumen insoluble in 86° B. naphtha	12.59
Per cent of fixed carbon	7.23
Per cent soluble in CS_2 (total bitumen)	99.97
Per cent of organic matter insoluble	.03
Per cent of inorganic matter insoluble	.00
Total	100.00

SUMMARY OF EXPERIMENTS IN SURFACE TREATMENT AT WASHINGTON, D. C.

All of the sections presented a satisfactory appearance when inspected early in March, 1913. The gravel pebbles have produced a mosaic effect on all of the sections excepting No. 3, where the gravel has been covered by a sand and oil mat. Section No. 3 has also shown a tendency to become quite muddy after a rain, although this trouble is not as evident as it was at first. The muddy condition is only of short duration and the surface soon dries out, forming a smooth mat under traffic. The surface of section No. 2 has also broken up in a few spots less than a foot in diameter, but this has evidently been due to the fact that the oil was not uniformly covered with gravel, and a few small bare places were left unprotected.

[1] Thin fluid, with strong naphtha odor.

[2] Slightly sticky.

In the cost data which follow no charge has been made for the distributor, which was lent for the purpose. Gravel cost $1.15 per ton; sand, 98 cents per cubic yard on the work; and the following unit prices for labor per day prevailed:

Common labor	$1.75
Cart and driver	3.50
Double team and driver	4.50
Distributor operator	4.00
Roller man	4.00

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TABLE 20.—*Materials and cost data for experiments in surface treatment at Washington, D. C.*

Section No.	Materials.	Area of section.	Quantity of material per square yard.			Cost per square yard.														Entire cost of section.
			Bitumen.	Gravel.	Sand.	Bitumen.	Gravel.	Sand.	Repairing surface.	Cleaning surface.	Loading distributor.	Heating bitumen.	Distributing.	Drying gravel.	Spreading gravel.	Spreading sand.	Rolling.	Freight on bitumen.	Total of items.	
		Sq. yds.	*Gals.*	*Cu. yds.*	*Cu. yds.*	*Cts.*	*Cts.*	*Cts.*	*Cts.*	*Cts.*	*Cts.*	*Cts.*	*Cts.*	*Cts.*	*Cts.*	*Cts.*	*Cts.*	*Cts.*	*Cts.*	
1	Refined water-gas tar	1,363	0.430	0.010	....	2.201	1.564	......	0.072	0.372	0.258	0.033	0.725	0.194	0.452	......	0.334	0.792	6.997	$95.37
2	Asphaltic petroleum	1,095	.411	.010	....	2.877	1.564	......	.215	.372	.180	.033	.725	......	.452	......	.334	.822	7.574	82.94
3	Residual petroleum	706	.425	.010	0.002	3.612	1.564	0.208	.215	.372	.327	.033	.725	......	.452	0.372	.334	.722	8.936	63.09
4	Asphaltic petroleum	1,321	.265	.010	....	1.987	1.564	......	.072	.372	.133	.033	.725	......	.452	......	.334	......	5.672	74.94

SUPPLEMENTARY REPORT OF EXPERIMENTS MADE AT CHEVY CHASE, MD., 1911.

TARS AND NATIVE AND OIL-ASPHALT PREPARATIONS.

The original report of these experiments is given in Circular No. 98. The following report covers the condition of the experiments up to February, 1913.

SECTION No. 1.—REFINED COAL TAR—PENETRATION METHOD.

At the time of the last inspection the seal coat had practically entirely worn off from the surface of this section over a width of about 20 feet out from the car tracks. This is the traveled portion. The remaining 20 feet, which is subjected to but slight travel, is still in perfect condition. During the summer months several ruts appeared in this untraveled portion. This was probably due to the fact that the stone heaved slightly as the tar became warm under the action of the sun. With the passing of a heavy load a rut $\frac{3}{8}$ inch deep was formed and cracks in the surface extended from 2 to 3 inches out from the rut. A surface treatment corresponding to the application of the seal coat will probably be made in the spring.

SECTION No. 2.—REFINED COAL TAR—MODIFIED GLADWELL METHOD.

Owing to excessive "bleeding," this section was treated with chips several times during the season to take up the surface tar. Just prior to the last inspection the surface was very hard and smooth, and a light coating of chips was spread to prevent horses from slipping on frosty mornings. The application of these chips was considered supplementary construction and not repair, and the charge has been made for it accordingly. At the present time this section is in excellent condition.

SECTION No. 3.—FLUXED NATIVE ASPHALT—PENETRATION METHOD.

No repairs were made to this section, and at this time it is smooth and in general resembles sheet asphalt.

SECTION No. 4.—GILSONITE OIL ASPHALT—PENETRATION METHOD.

In the spring of 1912 it seemed that repairs would probably be necessary to this section, but as the season advanced the entire surface "bled" slightly and uniformly and the apparently weak spots sealed over very satisfactorily. With the exception of slight inequalities in the surface, this roadway is in very good condition, and will probably require no repairs during the coming season.

SECTION No. 5.—OIL ASPHALT—PENETRATION METHOD.

In the spring of 1912 this section was badly broken up along the gutter on the west side and at various places in the body of the pavement. The surface over these weak spots was removed, and new stone was added and treated by the penetration method with two applications of $1\frac{1}{2}$ gallons and $\frac{1}{2}$ gallon per square yard, respectively. The

total amount of repairs was 286 square yards, and the total cost of these repairs was $260.26. The entire surface of the section improved during the season. At the present time only slight repairs will be required to put the surface in proper condition.

Section No. 6.—Oil Asphalt—Penetration Method.

With the exception of several depressions in the surface along the gutter, due to a settlement in the subgrade, this section is now in very satisfactory condition. No repairs other than those necessary to the depressions will be required.

Section No. 7, A and B.—Oil Asphalt—Penetration Method.

By the fall of 1912 a number of worn depressions had developed throughout these two sections. Although no raveling took place, the binder appeared to be "punky" and lifeless, and it was considered advisable to repair all these places and apply a cold surface treatment to the section which had never had a seal coat. The loose stones in the depressions were cut out to more solid material. The edges of the cut were painted with some of the hot bitumen which had been used in the original construction. The hole was then filled with new stone and the patch was made by the penetration method. In this manner 11 square feet of patches were made on A, the "two-coat section," and 52 square feet on B. The total cost of the former was $1.43 and of the latter $6.57.

As soon as the patching was completed the patches on A and the entire surface of B received a cold surface treatment with an asphaltic oil. The application was made on December 17, 1912, with the same distributor referred to above (see p. 21). The weather was fair, but, owing to the cold nights, the oil had to be slightly warmed before application. The surface was thoroughly cleaned before the oil was applied, and the application was immediately covered with a layer of limestone screenings and given a light rolling. The characteristics of the oil used are shown in the following table:

Table 21.—*Analysis of asphaltic petroleum* [1] *used in surface treatment of section No. 7–B.*

Specific gravity 25°/25° C	0.959
Flash point ° C	38
Burning point ° C	80
Viscosity, Engler 25° C., 50 c.c. specific	153.3
Per cent of loss 163° C. 5 hours (20 grams)	25.05
Float test of residue (50° C.) [2] (time)	1′ 29″
Per cent of total bitumen insoluble in 86° B. naphtha	7.84
Per cent of fixed carbon	4.96
Per cent soluble in CS_2 (total bitumen)	99.92
Per cent of organic matter insoluble	.08
Per cent of inorganic matter insoluble	.00
Total	100.00

[1] Thin fluid with strong naphtha odor.

[2] Soft, sticky, with slight flow.

TABLE 22.—*Materials and cost data for treatment with above oil.*

Area treated, square yards	925
Materials per square yard:	
Screenings, cubic yards	0.013
Oil, gallons	.29
Cost per square yard (cents):	
Screenings on work	2.79
Oil	2.04
Hauling oil	.49
Cleaning surface	.26
Loading distributor	.28
Warming oil	.10
Applying oil	.24
Spreading screenings	.49
Rolling	.54
Total	7.23

Beginning with March 4, 1912, regular counts of traffic on the Connecticut Avenue sections were made. The census was taken every 13 days over a full period of 24 hours, and on May 25 and 26 special counts were made in order to obtain figures upon the spring holiday traffic. A tabulation of the average and maximum of each class of traffic for 30 counts is given below. The east side of the road carries outgoing traffic and the west side incoming traffic. A vehicle entering upon and leaving the experimental sections without covering their entire length is classed as local traffic.

TABLE 23.—*Volume and character of traffic on Connecticut Avenue between Chevy Chase Circle and Bradley Lane.*

Vehicle.	East Side.				West Side.			
	Average.		Maximum.		Average.		Maximum.	
	Through.	Local.	Through.	Local.	Through.	Local.	Through.	Local.
Loaded 1-horse wagon	9	7	20	17	7	6	19	15
Unloaded 1-horse wagon	9	6	23	19	10	6	24	20
Loaded 2-horse wagon	12	5	44	20	13	5	82	19
Unloaded 2-horse wagon	26	4	78	20	13	3	44	19
Loaded 4-horse wagon	1	....	6	....	1	....	4	3
Unloaded 4-horse wagon	1	....	13	....	1	....	13	....
1-horse pleasure vehicle	9	3	18	5	10	2	20	6
2-horse pleasure vehicle	1	....	8	4	1	1	6	5
Rubber-tired horse vehicle	1	....	2	2	1	....	5	1
Saddle horse	2	1	4	7	3	1	8	7
Motor cycle	3	1	18	4	5	1	13	2
Motor runabout	22	6	43	15	19	8	44	20
Motor touring car	107	21	246	50	100	30	217	70
Loaded motor dray	3	3	9	9	3	2	8	8
Unloaded motor dray	2	1	5	5	3	1	7	5

SUPPLEMENTARY REPORT OF EXPERIMENTS MADE ON BRADLEY LANE, CHEVY CHASE, MD., 1911.

REFINED SEMIASPHALTIC OIL.

The original report of this experiment is to be found in Circular No. 98. At the time of the last inspection all three sections had been more or less cut through by traffic, and the stones under these bared spots were more or less moist. At these places the bituminous carpet had entirely disappeared, and it is probable that some supplementary treatment will be required over the entire distance during this spring.

The three sections have not, however, deteriorated uniformly. Section No. 1, as indicated in the original report, was subjected to heavy traffic, owing to the hauling of contractors' supplies. Owing to the thick carpet produced by the application of 0.92 gallon of oil to the square yard, together with the sand and fine screenings which were used to absorb the excess of oil, the bituminous carpet over this section was quite thick. As the roadway is narrow and traffic is confined to practically one track, this carpet was squeezed out so that two broad shallow ruts were formed. The material displaced by traffic lies in a mat from 1½ to 2½ inches thick on each side of the traveled road, where it serves no useful purpose. In order to prevent a further squeezing out of the bitumen in the wagon tracks, two areas were chosen near the middle of section No. 1, each 40 feet long, which were treated with chips ranging in size from 1 inch to ½ inch. The application was at the rate of 1 cubic yard to 48 square yards. The chips were forced into the roadway by a steam roller for the purpose of wedging and holding the material in place. This treatment was accomplished at a cost of 5 cents per square yard, and while it was effective in a measure and the displacement of the carpet was not as great as over the untreated portion, it was not considered of sufficient value to the surface to warrant its general application.

The thin layer within the traveled way has been cut through in section No. 1 in different places for two reasons. At several places the stone in the original roadway has continued to creep after the application of the surface coating, owing probably to subgrade weakness. In these places the bituminous carpet has entirely disappeared and depressions are worn in the pavement. In other places the carpet has worn away apparently from traffic only and the macadam surface beneath is still intact. Owing to the varied thickness of the cushion in its present condition, it will probably be necessary to remove it before an application of a new surface treatment.

Section No. 2 which has a one-coat treatment of 0.61 gallon to the square yard, has not suffered from the displacement of material as

have sections Nos. 1 and 3. With the exception of several small areas in the wagon tracks, where the carpet has been worn through, this section is in fair condition and a light supplementary bituminous treatment in the spring will probably be sufficient to carry it through the season without further care.

Section No. 3, which, like section No. 1, received a two-coat application amounting to 0.92 gallon per square yard, has not suffered as greatly from the lateral displacement of the carpet in the traveled portion since the traffic over this section is light. This displacement is not as serious as in the case of section No. 1, but has progressed sufficiently to be readily noticeable. An area 40 feet long was treated with coarse chips similar to the two areas already referred to in section No. 1, with various satisfactory results; but the treatment was not extended over the entire section because of its high cost.

Section No. 3 has suffered by reason of the mat breaking through in the road in several places, but it is possible that, if these are repaired and a light surface application is made to the entire section, no further repair will be required to carry it through the season.

SUPPLEMENTARY REPORT OF EXPERIMENTS MADE AT JAMAICA, N. Y., IN 1911.

OIL-CEMENT CONCRETE, OIL ASPHALT, TAR, AND FLUXED NATIVE ASPHALT.

The original report of these experiments is to be found in Circular No. 98. The following report covers the maintenance work which was carried out in May, 1912, and the results of an inspection made on December 19, 1912.

Experiment No. 1.—Oil-Cement Concrete.

Upon inspection in May, 1912, it was found that small worn places or holes, ranging in size from a few square inches to 2 or 3 square feet, had developed in the surface. That these may have been due in a way to the character of oil used is evidenced by the fact that they were more numerous in the first 90 feet, where a type of residual petroleum different from that in the remainder of the section was used. All of the concrete, however, appeared to be porous and low in tensile strength.

The edges of the expansion joints had been spalled off and at station 1+80, where the concrete adjoins a cobble gutter, the surface was badly worn for a length of 10 feet along the gutter. This hole was repaired by cutting out the concrete uniformly to a proper depth and making a patch with wood block. The oil asphalt hereafter referred to was used for a filler.

It was decided to give the entire section a surface treatment with several types of bituminous materials. The worn or pitted places were first thoroughly cleaned by brooming and were then painted with the tar-asphalt mixture, the analysis of which is given below. Chips were then spread in sufficient quantity to cover the bitumen lightly.

The entire concrete surface was then broomed and a bituminous seal coat of approximately ⅜ gallon per square yard was applied with hand-pouring pots. The seal coat was covered by an application of stone screenings, coarse sand, or stone chips free from dust.

In the case of the oil-asphalt section a paint coat composed of 1 part of the binder to 2 parts of naphtha was first applied to the surface of the concrete and the seal coat was poured over it.

The location and analyses of the several materials follow:

A, station 0+00 to station 0+24, refined coal tar, stone screenings.
B, station 0+24 to station 0+48, refined coal tar, sand.
C, station 0+48 to station 0+80, tar-asphalt preparation, sand.
D, station 0+80 to station 1+28, tar-asphalt preparation, stone screenings.
E, station 1+28 to station 1+52, tar-asphalt preparation, stone chips.
F, station 1+52 to station 1+67, oil asphalt, stone chips.
G, station 1+67 to station 1+80, tar-asphalt preparation, stone chips.

TABLE 24.—*Analyses of tar products used in surface treatment of oil-cement concrete at Jamaica, N. Y., 1911.*

Material.	Refined coal tar.		Tar-asphalt preparation.	
Specific gravity 25°/25° C.	1.202		1.177	
Float test 32° C. (time)	1′ 14″		1′ 30″	
Per cent of free carbon	15.91		14.57	
Per cent of loss at 105° C., 5 hours[1]			4.18	
Per cent of loss at 163° C., 5 hours[2] (fresh sample)			11.68	
Penetration of residue (25° C., 100 grams, 5 seconds) [mm.]			12.4	
	Per cent by volume.	Per cent by weight.	Per cent by volume.	Per cent by weight.
Distillation:				
First light oils to 110° C.	0.3	0.2	0.3	0.2
Second light oils 110–170° C.	.5	.3	.6	.4
Heavy oils 170–270° C.	21.8	18.1	18.2	15.6
Heavy oils 270–315° C.	13.2	11.2	[3] 9.7	8.5
Pitch residue	64.2	70.0	71.2	74.6
	100.0	99.8	100.0	99.3

[1] Brittle, lustrous surface, with soft semisolid content beneath.
[2] Brittle, lustrous surface, with hard semisolid content beneath.
[3] Showed 1.25 per cent insoluble in dimethyl sulphate; a 315–350° C. fraction showed 12.5 per cent and a 350–375° C. fraction showed 28.5 per cent insoluble in dimethyl sulphate. Results indicate from 10 to 15 per cent of oil-asphalt content.

TABLE 25.—*Analysis of oil asphalt*[1] *used in surface treatment of oil-cement concrete at Jamaica, N. Y., 1911.*

Specific gravity 25°/25° C	1.009
Melting point ° C	66.5
Penetration (5 seconds, 100 grams, 25° C.) [mm.]	4.2
Per cent of loss at 163° C., 5 hours (20 grams)	.22
Penetration of residue (as above)[2] [mm.]	3.7
Per cent of total bitumen insoluble in 86° B. naphtha	24.38
Per cent of fixed carbon	10.11
Per cent soluble in CS_2 (total bitumen)	99.75
Per cent of organic matter insoluble	.22
Per cent of inorganic matter insoluble	.03
Total	100.00

TABLE 26.—*Analysis of sand used in surface treatment of oil-cement concrete at Jamaica, N. Y., 1911.*

Passing ½-inch screen, retained on ¼-inch screen	4.3
Passing ¼-inch screen, retained on ⅛-inch screen	8.2
Passing ⅛-inch screen, retained on 10-mesh screen	11.1
Passing 10-mesh screen, retained on 20-mesh screen	16.7
Passing 20-mesh screen, retained on 30-mesh screen	17.2
Passing 30-mesh screen, retained on 50-mesh screen	25.4
Passing 50-mesh screen, retained on 80-mesh screen	11.5
Passing 80-mesh screen, retained on 100-mesh screen	2.1
Passing 100-mesh screen, retained on 200-mesh screen	2.0
Passing 200-mesh screen	1.5
	100.0
Per cent of voids in sand	29.6

[1] Sticky semisolid.

[2] Glossy surface.

TABLE 27.—*Materials and cost data for seal-coat work at Jamaica, N. Y., 1911.*

Experiment No.	Section.	Binding materials.	Length of section.	Area of section.	Quantities of materials per square yard.				Cost per square yard.											Entire cost of section.
					Stone screenings.	$\frac{3}{8}$-inch stone chips.	Sand.	Bitumen.	Stone screenings.[1]	$\frac{3}{8}$-inch stone chips.[1]	Sand.[1]	Bitumen.[1]	Patching surface.[1]	Sweeping surface.	Heating and applying bitumen.	Spreading stone or sand.	Superintendence.	Miscellaneous.	Total of items.	
			Feet.	*Sq. yds.*	*Cu. yds.*	*Cu. yds.*	*Cu. yds.*	*Gals.*	*Cts.*	*Cts.*	*Cts.*	*Cts.*	*Cts.*	*Cts.*	*Cts.*	*Cts.*	*Cts.*	*Cts.*	*Cts.*	
1	A	Refined coal tar	24	66.5	0.01			0.375	2.38			3.75	0.20	0.30	0.38	0.47	0.40	0.05	7.93	$5.27
1	B	.....do	24	66.5			0.01	.375			0.98	3.75	.20	.30	.38	.47	.40	.05	6.53	4.34
1	C	Tar-asphalt preparation	32	89.0			.01	.375			.98	4.13	.17	.30	.43	.35	.40	.05	6.81	6.06
1	D	.....do	48	136.0	.01			.375	2.38			4.13	.09	.30	.43	.35	.40	.05	8.13	11.06
1	E	.....do	24	86.0		0.01		.375		2.38		4.13	.05	.30	.43	.29	.40	.05	8.03	6.91
1	F	Oil-asphalt	15	53.0		.01		[2].580		2.38		[2]7.02	.15	.30	[3].59	.29	.40	.05	11.18	5.93
1	G	Tar-asphalt preparation	13	66.0		.01		.375		2.38		4.13		.30	.40	.47	.40	.05	8.13	5.37
4	A	Coal tar	70	179.0			.008	.280			.71	2.24		.35	.26	.26	.20		4.02	7.19
4	B	Tar-asphalt preparation	80	222.0			.010	.420			.98	4.62		.35	.39	.42	.40	.05	7.21	16.01

[1] Delivered on the work. [2] Includes the paint coat of 0.08 gallon at 1.27 cents per square yard. [3] Includes 0.2 cent for applying paint coat.

An inspection of these surface treatments in December showed that, on that portion where the refined coal tar had been used, the surface was fair and practically unbroken excepting for a bare place 2 by 3 feet at station 0 + 03 and a circular area 2 feet in diameter at station 0 + 47. The former was probably due to a depression which held water. There was some evidence that the bitumen had flowed slightly toward the sides of the road during hot weather.

Where the tar-asphalt preparation had been used, the surfacing was not in such good condition. From station 0 + 65 to station 0 + 98 it was badly spotted and about one-fourth of the bituminous coating was gone. From station 0 + 98 to station 1 + 42 it was in fair condition on the north side of the road, but about one-half of the coating was gone on the south side. An area of 3 by 4 feet at station 1 + 50 and another 6 by 8 feet at station 1 + 70 had worn off.

The small section treated with oil asphalt was in generally satisfactory condition.

Experiment No. 2.—Cut-back Oil Asphalt—Mixing Method.

The only repairs made to this section in May were due to a slight depression at station 4 + 94 caused by a yielding of the foundation over a house connection. This was repaired with a hot application of the oil asphalt, referred to in Table 25, and stone chips, after the surface of the depression had first been painted with a solution of the bitumen in naphtha. It was noted at the time that the advent of warm weather was causing the surface to shift and become wavy, and during the summer an attempt was made to pick up and reroll portions of it. When inspected in December, two narrow depressions about 1 inch in depth were noted in the first 65 feet of the section. From station 2 + 00 to station 4 + 50 a strip from 12 to 14 feet wide in the middle of the road was in good condition, but a rather objectionable wavy condition had developed for a width of 4 or 5 feet on each side of the road. The crests of these waves in places were elevated 4 inches above the troughs, but the surface bond was unbroken.

From station 4 + 50 to station 5 + 00 the pavement is excellent, and this is probably due to the fact that through an error a harder bitumen had been used in this location.

Experiment No. 3.—Fluxed Native Asphalt—Mixing Method.

This section is reported as being in perfect condition and having the appearance of a sheet asphalt pavement. A slight depression showing signs of wear at station 5 + 00 had been repaired in May, by means of a paint coat of oil-asphalt, in the manner described under experiment No. 2.

Experiment No. 4.—Refined Coal Tar—Mixing Method.

Upon inspection of this section in May it was interesting to note that, while the seal coat of oil-asphalt remained in very good condition, the seal coat of refined coal tar had entirely worn off, leaving the stone exposed and the surface rather porous. In applying a new seal coat to this portion, two materials were used after the surface had been well broomed.

From station 8 + 00 to station 8 + 70, the light coal tar, the characteristics of which are shown in Table 28, was applied by simply allowing it to run from the barrel and brooming it over the surface. It was applied at the rate of 0.28 gallon per square yard and immediately covered with sand.

From station 8 + 70 to station 9 + 50 a seal coat of the tar-asphalt preparation used in experiment No. 1 was applied hot by means of hand-pouring pots. This application was also covered with sand.

Table 28.—*Analysis of coal tar used as a seal coat on experiment No. 4.*

Specific gravity 25°/25° C		1.160
Per cent of free carbon		9.31
Distillation:	Per cent by volume.	Per cent by weight.
Ammoniacal water	3.3	2.9
First light oils to 110° C	3.6	2.7
Second light oils 110–170° C	.9	.5
Heavy oils 170–270° C	[1] 18.0	15.0
Heavy oils 270–315°C	[2] 8.8	7.4
Pitch residue	65.4	70.8
Total	100.0	99.3

When inspected in December, the surface of this entire experiment was smooth, uniform, and free from depressions, and no failures of any nature were evident. From station 8 + 00 to station 9 + 50, where the new seal coats had been applied, the surface had a slightly mosaic appearance.

Experiment No. 5.—Cut-Back Oil Asphalt—Mixing Method.

The surface of this section showed a tendency to disintegrate in any depressions where water collected and by May two rather large holes were found at station 13 + 37. The surface was cut down to the foundation stone and the edges of the hole were painted with the solution of oil asphalt in naphtha referred to in experiment No. 1. The hole was then filled with "Topeka" asphalt paving mixture, which was being used near by. It was spread to a depth of 3 inches and tamped into place with hand tampers.

[1] Three-fourths solid. [2] One-half solid.

When inspected in December, the surface presented a smooth appearance, resembling sheet asphalt, excepting for the fact that it had become slightly wavy on the north edge.

Experiment No. 6.—Oil Asphalt—Penetration Method.

The only repairs necessary to this section in May were due to the fact that the wheel of one of three heavily loaded steel-tired trucks had stripped a small section of the seal coat at station 15 + 44 on May 11. The repairs were made with the tar-asphalt preparation and chips.

Experiment No. 7.—Refined Coal Tar—Penetration Method.

The only repairs necessary to this section in May were due to slight breaks in the seal coat at station 15 + 48, which were repaired with tar-asphalt preparation and chips, and at stations 15 + 70, 16 + 00, and 16 + 59, which were repaired with tar-asphalt preparation and sand. The stripping at station 16 + 00 was due to the steel-tired trucks referred to as damaging experiment No. 6.

A telephone conduit had been laid across the road at station 16 + 36, and this necessitated the replacing of the surface over the filled trench. The repairs were made by the penetration method, using the tar-asphalt preparation for a binder. No cost data were kept on this work, however, for the reason that the defect was not due to the deterioration of the road.

Experiment No. 8.—Fluxed Native Asphalt—Penetration Method.

The surface of this section was quite soft in the early summer, particularly on the northern half of the road, and the wheels of the heavy truck previously mentioned picked it up at station 17 + 00 and at station 17 + 13. There was also a worn place at station 17 + 00 and at the joint with the preceding section. Repairs were made with the tar-asphalt preparation and sand as heretofore described.

Experiment No. 9.—Oil Asphalt—Penetration Method.

The wheels of the above-mentioned trucks had picked up the seal coat at station 18 + 50 in three places and had removed a strip 3 inches wide from station 19 + 80 to station 20 + 00. The surface had also caved in in a small place at station 19 + 25 owing to a settlement of the foundation over an old sewer trench running longitudinally along the center of the road. The pavement was opened up making a trench 12 feet long, into which sand was forced by flushing with water. In order to allow the "back fill" to settle thoroughly the replacement of the surface was postponed.

The three small stripped places at station 18 + 50 were repaired with the tar-asphalt preparation and sand, but nothing was done to the 20-foot strip which was merely slight damage.

When inspected in December, 1912, the surfaces of experiments Nos. 6, 7, 8, and 9 were all smooth and in an excellent state. Experiment No. 7 presented a slightly mosaic appearance, while experiments Nos. 6, 8, and 9 resembled sheet asphalt. The only apparent defects in any of these sections are a few humps, probably due to an excess of bitumen.

The cost data for the repairs to all of the sections are given in the following tables and are based upon the following unit prices:

Foreman (per 8-hour day)	$4.00
Laborer (per 8-hour day)	2.50
Horse and cart with driver (per 8-hour day)	3.50
Heating kettles (140 gallons capacity) (per 8-hour day)	.15
Small tools (per day per man)	.03

TABLE 29.—*Materials and cost data for wood-block patch in experiment No. 1.*

Area of patch, square yards	2.22
Materials per square yard:	
Sand, cubic yards	0.03
Paint coat, gallons	.15
Wood block, number	54.00
Bitumen, gallons	2.50
⅜-inch stone, cubic yards	.02
Cost per square yard (cents):	
Sand (delivered on work)	2.94
Paint coat (delivered on work)	2.37
Wood blocks (delivered on work)	189.00
Bitumen (delivered on work)	28.75
⅜-inch stone (delivered on work)	4.76
Cutting out surface of concrete	42.30
Laying block and tamping	12.93
Pouring bitumen	3.51
Spreading sand and chips	1.00
Total	287.56
Total cost of entire patch	4.38

TABLE 30.—*Materials and cost data for patching bituminous sections at Jamaica, N. Y., 1912.*

Experiment No.	Station No.	Area of patch.	Bituminous binder used.	Aggregate used.	Quantity of material per square yard.				Cost per square yard.								Cost of repairs to section.
					Paint coat.	Binder.	Chips.	Sand.	Binder.	Paint.	Sand.	Chips.	Labor.	Superintendence.	Total of items.	Cost of patch.	
		Sq. yds.			*Gals.*	*Gals.*	*Cu. yds.*	*Cu. yds.*	*Cents.*	*Cents.*	*Cents.*	*Cents.*	*Cents.*	*Cents.*	*Cents.*	*Cents.*	*Cents.*
2	4+94	0.66	Oil asphalt	Chips	0.08	0.5	0.01		5.75	1.26		2.38	3.00	0.50	12.89	8.51	8.51
3	5+00	1.66	do	do	.08	.5	.01		5.75	1.26		2.38	3.00	.50	12.89	21.40	21.40
5	13+20	.11	Tar asphalt	do		.38	.01		4.13			2.38	2.70	.50	9.71	1.08	
	13+37	3.33	do	Topeka	.15	[1] .08		0.02	[2] 100.00	2.37	1.96		22.14	.50	126.97	423.00	424.08
6	15+44	.02	do	Chips		.38	.01		4.13			2.38	2.70	.50	9.71	.19	
	15+48	.14	do	do		.38	.01		4.13			2.38	2.70	.50	9.71	1.36	
	15+47	.06	do	Sand		.38		.01	4.13		.98		2.70	.50	8.31	.50	2.05
7	16+00	.006	do	do		.38		.01	4.13		.98		2.70	.50	8.31	.05	
	15+70	.02	do	do		.38		.01	4.13		.98		2.70	.50	8.31	.17	
	16+59	.007	do	do		.38		.01	4.13		.98		2.70	.50	8.31	.06	.28
8	17+13	.05	do	do		.38		.01	4.13		.98		2.70	.50	8.31	.42	
	17+02	.05	do	do		.38		.01	4.13		.98		2.70	.50	8.31	.42	
	17+00	1.00	do	do		.38		.01	4.13		.98		2.70	.50	8.31	8.31	9.15
9	18+50	.05	do	do		.38		.01	4.13		.98		2.70	.50	8.31	.42	
	18+50	.02	do	do		.38		.01	4.13		.98		2.70	.50	8.31	.17	.59

[1] Topeka mixture, cubic yards per square yard.

[2] Topeka mixture in place.

SUPPLEMENTARY REPORT OF EXPERIMENTS MADE AT ITHACA, N. Y., IN 1909, 1910, AND 1911.

EXPERIMENTS ON FOREST HOME DRIVE—TAR, OIL, OIL ASPHALT, BRICK, CEMENT, AND SLAG.

Detailed reports of these experiments are to be found in Circulars Nos. 92, 94, and 98, and the report of an inspection and repairs to sections then completed is also given in Circular No. 98. The following report gives the general condition of all the sections at the time the annual repairs were made in October, 1912. Owing to long-continued unfavorable and cold weather, the work was finally abandoned before all the contemplated repairs had been made. The experiments will hereafter be discussed under their *section* numbers, which is the order of their location, and the experiment number will be disregarded.

Section No. 1.—Refined Coal Tar—Penetration Method.

The surface of this section remains in excellent condition. A large depression, without any break in the surface, has formed at the southeast intersection with Central Avenue. This causes a lack of proper drainage at the intersection and is to be repaired.

Section No. 2.—Refined Coal Tar—Mixing Method. Section No. 3.—Brick. Section No. 4.—Artificial Oil Asphalt—Mixing Method.

These three sections have been seriously affected by recent changes in the grade and location of Forest Home Drive. Sections Nos. 3 and 4 have both been entirely removed. It is planned to relay the brick section on the new location and to reconstruct the oil-asphalt section with a material similar to that originally used. Both sections were in excellent condition when taken up. The eastern half of section No. 2 had failed throughout a large area, owing mainly to the building operations along the roadside. This part of the section will be constructed on a new grade, and on the remainder of the section a number of depressions will have to be repaired.

Section No. 5.—Refined Semiasphaltic Oil—Penetration Method.

Except for a slight unevenness in some parts of the surface, this section continues in satisfactory condition and no repairs are necessary. About 30 feet at the west end of the section will be removed in changing the grade of the drive.

Section No. 6.—Semisolid Refined Semiasphaltic Oil—Penetration Method.

With the exception of a small worn hole, which will require about 4 square feet of new surfacing, this section continues in excellent condition.

Section No. 7.—Kentucky Rock Asphalt.

The general character of this section up to date is good. There are, however, a number of small depressions, mainly throughout the eastern half of the section, which should be repaired. The joint between this section and the preceding one is also worn.

Section No. 8.—Refined Water-Gas Tar—Penetration Method. Section No. 9.—Refined Semiasphaltic Oil—Penetration Method. Section No. 10.—Refined Water-Gas Tar and Slag—Penetration Method.

The surfaces of sections Nos. 8, 9, and 10 were in excellent condition at the time of inspection. Section No. 9 has a considerably softer surface than the others and calk marks are noticeable throughout. No repairs were required on any of these sections.

Section No. 11.—Open-Hearth Slag.

During the winter and spring clay continued to work to the surface of this section, causing a disagreeably muddy condition. This seems to have worked off to some extent during the summer, and when inspected in October the section was in fair condition.

Section No. 12.—Artificial Oil Asphalt—Mixing Method.

The surface of this section has a mosaic appearance due to the fact that the large stones show. There is no sign of failure, but a seal coat of the material used in the original construction will be applied in the spring.

Sections Nos. 13, 14, and 15.—Concrete.

No inspection could be made of these sections owing to the fact that they had been given a hot-oil surface treatment by the State highway department, which has jurisdiction over this portion of the road.

EXPERIMENTS ON EAST AND SOUTH AVENUES.

Sections Nos. 16 and 17.—Oil Asphalt—Penetration and Prepared Filler Methods.

These two sections were constructed with the same binder, and their difference consisted in the fact that the former was constructed by the regular penetration method, while the upper course of uncoated stone in the latter section was filled by harrowing in bitumen-coated stone chips. When inspected for the purpose of making repairs, it was found that both sections had failed in a number of places. Two large ruts in the traveled way extended throughout the greater part of the length of section No. 16 and there were numerous raveled spots of varying size in both sections.

The repairs consisted of deep patches in which the loose material was excavated to a depth of from 3 to 5 inches and shallow patches

in which a paint coat was applied to slight unbroken depressions. In making the former the loose stone was cut back until a firmly bound surface was reached. The edges of the hole were thoroughly cleaned and painted with hot bitumen, and when the hole did not exceed 3 inches in depth the bottom was also painted. The patch was then made by filling the hole with clean stone ranging in size from $\frac{3}{4}$ inch to $1\frac{1}{4}$ inches in longest dimension. The patch was built up by the penetration method and finished with a seal coat.

Where there was simply a depression in the roadway over which no appreciable deterioration of the surface texture had taken place, a paint coat was applied and covered with screenings.

Section No. 16 required 342 square feet of deep patches and 218 square feet of paint coat work, and section No. 17 required 131 square feet of deep patches. Deep patches cost from $5\frac{1}{2}$ to $9\frac{1}{2}$ cents per square foot, depending upon the depth of patch, and paint coat work cost approximately 1.4 cents per square foot. In both cases the cost of rolling is not included.

Sections Nos. 18 and 19.—Oil Asphalt—Mixing and Prepared Filler Methods.

The same binder was used in both of these sections, but No. 18 was constructed by the mixing method and No. 19 by the same method as No. 17. The bulk of the repairs was required on the mixing method experiment and the stone for patching was mixed with the bitumen before being placed. The mixing was done by hand in 2 cubic foot batches and the proportions were 18 gallons of bitumen to the cubic yard of stone.

In addition to the deep patches and paint coat work described under repairs to the previous sections, shallow patches were made by first pouring a paint coat over the low area. When this coat had been thoroughly broomed a layer of the mixed material was laid and finished in the usual manner for mixing work. This work was done along the concrete gutter, which had been so constructed as to project above the pavement.

There was a total of 593 square feet of deep patches, 225 square feet of shallow patches, and 196 square feet of paint coat work. Exclusive of rolling, the deep patches cost 9.2 cents per square foot, shallow patches 5.5 cents per square foot, and paint coat work 1.5 cents per square foot.

Sections Nos. 20 and 21.—Semisolid Refined Semiasphaltic Oil—Mixing Method.

These two sections were laid with the same material, with the only difference that No. 20 was finished with a seal coat, while No. 21 was not. Practically all of the repairs were required upon the section where the seal coat had been omitted. The patches were made with

mixed material in exactly the same manner as has been described under section No. 18. There were 280 square feet of deep patches, 135 square feet of shallow patches along gutters, and 50 square feet of paint coat work, at the same costs given for the previous section.

Sections Nos. 22 and 23.—Refined Water-Gas Tar—Mixing Method.

These two sections have failed in large areas throughout their entire lengths. Patches were all made by the mixing method as previously described, but, on account of a long period of wet weather before the repairs were entirely completed, the surface was too damp to permit any paint coat work over shallow depressions.

Section No. 22 required 160 square feet of deep patches and 305 square feet of shallow patches, while section No. 23 required 326 square feet of deep patches and 148 square feet of shallow ones. The cost ranged from 7.5 cents per square foot for shallow work to 9.5 cents for deep work.

Section No. 24.—Asphalt Block.

This section continued in excellent condition excepting for a small area adjacent to the east curb and 23.5 feet from the south end of the section, where the blocks were loose and a number of them had cracked. The blocks were removed and the foundation was excavated to a depth of 6½ inches below the finished surface. It was found that about an inch of sand-cement below the block had never set, and beneath this there was nothing but soft, springy clay at the point of worst failure. A 4-inch layer of 1 : 2 : 4 Portland cement concrete was put in and covered with a ½-inch sand cushion upon which the new blocks were set. Fifty-nine new blocks were used and the total cost of repair was $7.01, or at the rate of 45 cents per square foot.

Section No. 25.—Oil Asphalt—Mixing Method.

While the north half of this section remained in fair condition, the south half had raveled in a number of fairly large areas. The conditions in this part of the section are particularly severe owing to the fact that large quantities of mud are brought on from the unimproved portion of South Avenue. The patches were made with mixed material in the manner described for section No. 18. Wet weather and the fact that traffic could not be kept off interfered with the success of the work. It was found impracticable to make a seal coat adhere satisfactorily, and so this form of patching was omitted on this section. A total of 814 square feet of patches over 2 inches in depth and 59 square feet of shallower patches was made at a cost of from 9.5 cents to 10 cents per square foot, exclusive of rolling.

Sections Nos. 26, 27, and 28.—Refined Asphaltic Preparation.

The surface of section No. 26 had been badly marred by openings for water pipes, but the undisturbed portions of the surface were in good condition. Section No. 27, upon which it had been necessary to omit a seal coat, had developed ruts and raveled spots throughout the traveled portion. Section No. 28 required practically no repairs. Repairs were made by the penetration method as described for sections Nos. 16 and 17. There were 995 square feet of deep patches and 147 square feet of shallow patches along the gutters. Exclusive of rolling, the former cost 9.5 cents per square foot and the latter 5.5 cents per square foot.

Section No. 29.—Oil Asphalt—Mixing Method.

The only defect noted in this section was a small worn depression of about 1 square foot in area. On account of continued bad weather the season's repairs were discontinued before this was attended to. Otherwise the section presented a smooth, firm surface.

Section No. 30.—Refined Coal Tar—Penetration Method.

The surface of this section also continues in excellent condition and no repairs were found necessary.

SUPPLEMENTARY REPORT OF EXPERIMENTS MADE AT NEW YORK, N. Y., AND RIDGEWOOD, N. J., 1910.

OIL-CEMENT CONCRETE.

The original report of these experiments, including the report of an inspection made in January, 1911, is to be found in Circular No. 94, and a report of a later inspection in December, 1911, is given in Circular No. 98. The following report covers inspections made on December 20, 1912.

Experiments at New York.

The general condition of the surface was about the same as when inspected a year ago and the worn places about the joints do not seem to have worn to any extent during the year.

From station 2 + 10 to station 2 + 43, at the intersection with Newark Street, the pavement has cracked badly both longitudinally and transversely, forming something like a spider web of cracks from the intersection of the two street centers.

A street cut had recently been made through the south half of the street at station 4 + 18.

Experiments at Ridgewood, N. J.

The floors of both bridges continue in good condition, and there is no apparent change since the inspection a year ago.

SUPPLEMENTARY REPORT OF AN EXPERIMENT MADE AT BOISE, IDAHO, 1910.

OIL-GRAVEL MACADAM.

The original report of this experiment appears in Circular No. 94, and a report of an inspection made in January, 1912, was published in Circular No. 98. The road was again inspected in October, 1912, and conditions were rated as follows:

The road shows three types of defects:

(1) Shallow broad ruts becoming deeper and narrower at distant intervals and in one or two places cutting completely through the surface. The broad ruts are present, particularly on that portion of the road which lies on the bench south of the river.

(2) Patches of worn surface with large gravel stones bare in the aggregate. These defects are present at distant intervals over the whole road, but especially on the lower part of the road near the turn and south of the bridge.

(3) A few humps and a considerable number of depressions, which are not due to wear, because the surface is smooth and solid. These defects appear south of the bridge and at the corner where the grade begins at the south of the river.

At times a combination of the three defects above noted may be observed. The ruts are not bad, except in one or two short places. The disintegrated patches seldom exceed 4 by 10 feet. The humps and hollows are from 1 to 4 inches in greatest depth. Where they are numerous, passing traffic is badly shaken. There are many ruts outside the traveled way.

There is certainly no failure of the bituminous material here. Too large gravel in the surface and a poor foundation are apparent causes of defective conditions.

The foundation has not settled as a whole, for the crown is still present throughout, and the road looks in places like a sheet asphalt pavement.

SUPPLEMENTARY REPORT OF AN EXPERIMENT MADE AT AMES, IOWA, 1910.

OIL-ASPHALT GRAVEL.

The original report of this experiment may be found in Circular No. 94, and a report of an inspection in 1912 is given in Circular No. 98. The following report covers an inspection made on October 14, 1912.

Travel has used more of the east side of the road than the west, and this portion appears to be in better condition. The superficial skin is more compact and smoother and does not scrape up with the

boot or pick as easily as the west side, where travel has been more scattered.

There was a layer of fine dust on the road, possibly due to disintegration of the surface, but more likely to the dropping of mud from teams from other portions of the highway on this short section. The traffic is rather heavy, owing to construction work on other portions of the campus. The only maintenance which this road has received has been occasional dragging.

A small hole dug in the middle of the road showed that there had been good penetration of bitumen to a depth of at least 3 inches, but the mixture was not homogeneous. On the west side near the curb, where the travel had been light, the bitumen appeared to have retained more life, even where it was exposed on the surface in patches.

SUPPLEMENTARY REPORT OF EXPERIMENTS MADE AT KNOXVILLE, TENN., 1910.

TAR AND OIL PREPARATIONS.

The original report of these experiments is to be found in Circular No. 94, and the report of an inspection made in November, 1911, is given in Circular No. 98. The following is the report of an inspection made on January 11, 1913, after a period of heavy rain. All of the sections were covered with mud brought on from intersecting clay roads.

Section No. 1 had raveled throughout its entire area and had numerous depressions in which stone had been swept out by traffic. This section will be resurfaced during this spring.

Section No. 2 varied in character. The eastern half was, in general, satisfactory throughout, excepting where the surface had been broken for a water connection at about 150 feet from the end. The western half, however, showed a number of small raveled places, and these were particularly in evidence in the vicinity of the intersections with clay roads. Surrounding conditions are no doubt partially responsible for some of the failures which have occurred.

Section No. 3 presents a smooth, well-bound surface, and is in practically the same condition as reported a year ago.

SUPPLEMENTARY REPORT OF EXPERIMENTS MADE AT YOUNGSTOWN, OHIO, 1909.

SLAG, SLAG AND LIME, SLAG AND WASTE SULPHITE LIQUOR PREPARATION, AND SLAG AND TAR.

The original report of these experiments appears in Circular No. 92, and reports of inspections made in January and December, 1911, are to be found in Circulars Nos. 94 and 98, respectively. The following

notes were taken from an inspection made on December 11, 1912. The sections are discussed in the order of their *section* numbers, beginning at Mahoning Avenue.

SECTION NO. 1.—BLAST-FURNACE SLAG.

The first 50 or 60 feet of this section has apparently been scarified or picked down about 1½ or 2 inches, and at the date of this inspection this first 50 or 60 feet presented a loose and raveled appearance over the entire width of the surface. The remainder of section No. 1 looked extremely good. There was slight evidence of wheel ruts, probably owing entirely to the wear of traffic. These ruts were probably not over one-half inch in depth and were from 8 to 12 inches wide. This section in general appeared to be the best of all the sections.

SECTION NO. 2.—BLAST-FURNACE SLAG AND LIME.

This section is in good condition with the exception of ruts somewhat like those described in section No. 1.

SECTION NO. 3.—BLAST-FURNACE SLAG AND WASTE SULPHITE LIQUOR PREPARATION.

Opposite this section on the west side considerable grading has been going on, and the whole section, at the time of inspection, was covered with more or less clay. The section presented a somewhat mottled appearance, with some of the coarser stone showing through the clay, but the clay had an average thickness of probably three-eighths inch. Apparently for the purpose of cleaning the clay from the surface, a road machine or some form of scraper had been run over the west third of the road surface and had loosened it somewhat, but, aside from the slight unevenness described above as a mottled appearance, the surface looks good and there is no raveling.

SECTION NO. 4.—BLAST-FURNACE SLAG AND REFINED COKE-OVEN TAR.

The north third and the south third of this section present a very good appearance. The middle third on the fill has settled unevenly. In some spots there is a deficiency of tar and in a few places in the wheel tracks the tar is practically all gone and there is more or less an appearance of disintegration as a result.

SECTION NO. 5.—BLAST-FURNACE SLAG.

Ruts are a little more apparent on this section than on the others, but there is no ravel. Section No. 5 has worn down about 1½ inches below section No. 4 where they join.

SECTION NO. 6.—BLAST-FURNACE SLAG.

This section is in fair condition, with a slight indication of ruts. The surface was covered by a film of dust about one-fourth inch thick. No raveled spots were evident.

Section No. 7.—Blast-Furnace and Open-Hearth Slag.

This section is also in fair condition, with a slight indication of ruts. A film of dust about one-fourth inch in thickness, which would be muddy when wet, covers the surface. There is a slight settlement on this section over the fill.

SUPPLEMENTARY REPORT OF EXPERIMENTS MADE AT NEWTON, MASS., 1908.

ASPHALTIC PREPARATIONS, TAR PREPARATIONS, RESIDUAL OIL, AND MOLASSES-OIL-LIME.

The original report of these experiments is given in Circular No. 90, and reports of inspections have been published in Circulars Nos. 92, 94, and 98. The following report covers an inspection made on November 8, 1912.

Experiments Nos. 1, 2, 3, 4, 5, 6, and 7.—Asphaltic Preparation—Mixing Method.

The first four of these sections were so badly worn as to require resurfacing. There are many depressions and more than one-half of each section has lost its bituminous macadam surfacing. Experiments Nos. 3 and 4 are possibly in a little better condition than Nos. 1 and 2.

In experiment No. 5, the eastern half of the roadway needs resurfacing, while the western half continues in very good condition. It might be noted that experiments Nos. 1, 2, 3, and 4 were completed without the application of a seal coat, while experiment No. 5 had a seal coat of the binder used in construction, and No. 6 had a seal coat of hot refined coal tar. This section continues in very good condition.

Experiment No. 7, in which the bitumen content was increased, requires three patches of about 4 square feet each, but is otherwise in good condition.

Experiment No. 8.—Residual Oil—Mixing Method.

This section continues in good condition, excepting for the need of two patches at Langdon Street. These places have areas of 1 and 2 square feet, respectively.

Experiments Nos. 9 and 10.—Refined Water-Gas Tar—Mixing Method.

Section No. 9 is worn through in five places and should be patched. The total area requiring patching is about 30 square feet. No. 10 is in almost perfect condition, having only one small hole about 10 inches in diameter.

Experiment No. 11.—Molasses-Oil-Lime.

About 50 per cent of this section continues in fairly good condition, but is somewhat rough. The remainder of the section should be resurfaced.

SUPPLEMENTARY REPORT OF EXPERIMENTS MADE AT GARDEN CITY, DODGE CITY, BUCKLIN, AND FORD, KANS., 1908.

SAND CLAY.

The original report of these experiments appears in Circular No. 90, and reports of inspections made in 1909, 1910, and 1911 appear in Circulars Nos. 92, 94, and 98, respectively. The following are reports of inspections made in 1912.

Experiment at Garden City.

The road was inspected on October 28, 1912, and was found to be in very good condition. It was closely bonded, free from ruts or dust, and had a uniform crown and excellent wearing surface. The edges of the surfaced way showed good alignment and no broken places from the attacks of traffic. The road is dragged after the rains, and new material is added to keep it in good repair. It carries a mixed traffic, with maximum load of about 2 tons, although about 600 feet at the north end carries a continuous traffic, due to hauling sand. By following the same track this has worn twin ruts about 1 inch deep into the roadway, but the bond is not broken. The cost of maintaining the road has been small, as it is near a gypsum clay pit.

Experiment at Dodge City.

The road was inspected on October 28, 1912, and found to be in good condition with the exception of about 1,000 feet at the north end, which is rather badly broken up and full of holes. These defective places appear in the wheel tracks at various intervals, and occasionally the bond is broken all the way across the surfaced width and cut through to the original sand foundation. The rest of the section is in excellent shape, carrying the loads without developing ruts or broken places in the wheel tracks. It has a good crown and a uniform cross section. It is hard and shows an excellent wearing surface. The ditches are cleaned out all the way and are of standard width. The road is dragged after the rains and a little sand from the sides is carried over the surfaced way to be mixed by traffic with the gumbo. Moreover, some new material was added to the defective places last spring, when the road was considered very satisfactory and smooth all the way. The road carries a mixed traffic with a maximum load of from 75 to 80 bushels of wheat. The behavior of the north end of the road is evidently not due to neglect, but to the fact that the character and volume of traffic is greater over this portion. It is evidently not equal to the burdens it has to carry.

Experiment at Bucklin.

The road was inspected on October 29, 1912, and was reported to be in fair condition with the exceptions noted below.

Broken places in the wheel tracks resulting in chuck holes varying in size from incipient breaks to holes entirely through the surfacing were discovered in a number of places, excepting in that part of the course at the north end and for a distance of about 500 feet south of the bridge across the Arkansas River, which was in ideal condition. It was closely bonded and free from ruts, dust, or broken places, and had a good crown and alignment.

This is a much-traveled road between Dodge City and Bucklin. It carries a mixed traffic of light and heavy vehicles and automobiles. The maximum load is represented by from 75 to 80 bushels of wheat. The recent dry weather and greater amount of traffic in marketing the wheat has resulted in developing defective places in the roadway as noted above. It is reported to have been kept in excellent condition until quite lately by the use of the road drag. No new material has been added this season.

Experiment at Ford.

This road was inspected on October 29, 1912, and was found to be in good condition and free from ruts, dust, or broken places. It was constructed from a natural soil, having a combination of minerals, which bond closely, and it shows an excellent wearing surface like many of the natural dirt roads of Kansas. It responds promptly to a little treatment with the drag, and has been shaped once this season with the road grader. No new material has been added since it was constructed, except to fill up a depression at the junction of the road with the floor of the bridge across the Arkansas River.

This road is subjected to a mixed traffic of light and heavy vehicles and automobiles, and carries a maximum load of about 2 tons.

SUPPLEMENTARY REPORT OF EXPERIMENT MADE AT INDEPENDENCE, KANS., 1908.

OIL-ASPHALT EARTH ROAD.

The original report of this experiment appears in Circular No. 90, and reports of inspections made in February, 1910, and February and December, 1911, appear in Circulars Nos. 92, 94, and 98, respectively. The following report is based upon an inspection made on October 26, 1912.

The road was found to be in poor condition. On the eastern end of Tonopah Drive for one block there are two lines of traffic, separated by a ridge of natural dirt which has been hauled in by wagons. This part has the appearance of a poorly constructed dirt road. The traffic has spread the dirt over the northern half of this section, entirely covering up the earth-asphalt road. The southern half of this section is about as constructed, but the ruts and rough surface would indicate that the road is soft and spongy during wet weather. The western

end of Tonopah Drive is in fair condition, with one line of traffic in the center, which has hammered it down fairly smooth and hard. This section has a good crown and uniform cross section with competent ditches. That part of the improvement on Fourth Street has been pretty well covered up with dirt which came from the ditches or was hauled on in wagons to fill up a water-washed gully in the center of the roadway. Some quite large stones are scattered promiscuously over the roadway. At the northern end at the intersection of a side street it is covered entirely with dirt carried on by the road machine. About all of the earth-asphalt road exposed to view on Fourth Street is one-half the width and on the western side, and this is the only part used by traffic. It is in about the same condition as reported in December, 1911, except for dust ground up by traffic during the recent dry weather. Nothing whatever has been done to maintain the road since it was constructed.

SUPPLEMENTARY REPORT OF EXPERIMENT MADE AT BOWLING GREEN, KY., 1907.

KENTUCKY ROCK ASPHALT.

The original report of this experiment is to be found in Circular No. 89, and reports of inspections occur in Circulars Nos. 90, 92, 94, and 98. The section was again inspected on January 10, 1913, and the following notes were taken.

The surface in general remains intact, smooth, and hard, but bears evidence of not having had any attention. Several inches of mud had accumulated on both sides of the eastern portion of the road. The hole mentioned in previous reports remains the same, and a shallow rut about midway between the crown and south side is in evidence in several places throughout the eastern half of the section.

The western half of the section shows three small worn places in which the asphalt has disintegrated. These are located at approximately 3 feet, 25 feet, and 45 feet from the west end, and there are also three small shallow depressions on the crown at the middle of the section. These slight defects can be repaired at a very small cost and the section thus put in excellent condition.

ADDITIONAL COPIES of this publication may be procured from the SUPERINTENDENT OF DOCUMENTS, Government Printing Office, Washington, D. C., at 5 cents per copy

Issued August 19, 1913.

U. S. DEPARTMENT OF AGRICULTURE,

OFFICE OF PUBLIC ROADS—Circular No. 100.

LOGAN WALLER PAGE, Director.

TYPICAL SPECIFICATIONS FOR THE FABRICATION AND ERECTION OF STEEL HIGHWAY BRIDGES.

PREPARED BY THE OFFICE OF PUBLIC ROADS.

WASHINGTON:
GOVERNMENT PRINTING OFFICE.
1913.

LETTER OF TRANSMITTAL.

U. S. Department of Agriculture,
Office of Public Roads,
Washington, D. C., May 14, 1913.

Sir: I have the honor to transmit herewith a manuscript entitled "Typical Specifications for the Fabrication and Erection of Steel Highway Bridges," which has been prepared in this office with the view of furnishing a suitable guide for local highway officials in fixing requirements to which bridge structures must conform.

In the past many steel bridges have been very poorly constructed, and it is believed that lack of information on the part of highway officials concerning proper specifications for this class of work has been in a large measure responsible for the unsatisfactory results. In order, therefore, to make the specifications contained in this manuscript more readily available for the use of such officials, I respectfully request that the manuscript be published as Circular No. 100 of this office.

Respectfully,

L. W. Page,
Director.

Hon. D. F. Houston,
Secretary of Agriculture.

CONTENTS.

TYPICAL SPECIFICATIONS FOR THE FABRICATION AND ERECTION OF STEEL HIGHWAY BRIDGES.

DESCRIPTION OF PROJECT.

The contract of which these specifications form a part contemplates the construction of a steel highway bridge over.......... in .... township, ... County, State of ....

The abutments and piers to consist of .... masonry.

The total length of the superstructure to be .... feet.

The height above mean low water to be .... feet.

The number of spans to be ....

The width of roadway to be .... feet.

The assumed loading to be class........... (The loading classification contained in these specifications is to be followed.)

The floor to be of ...., thickness .... inches.

Paint { First coat to be ....
Second coat to be ....

The structure to be entirely completed on or before ...., 19......

GENERAL.

The Engineer.

The term "engineer," as hereinafter employed, shall be interpreted to mean the duly authorized representative of the officials legally responsible for the work to be performed under these specifications, and the decisions of the said engineer upon all questions herein left to his discretion shall be final and conclusive.

Engineer's General Drawings.

The general drawings which form a part of these specifications are on file at ---------- and consist of—

Sheet No. 1, showing --

Sheet No. 2, showing --

Sheet No. 3, showing --

Sheet No. 4, showing --

They, together with these specifications, embody all the information which will be furnished for the guidance of contractors.

Contractor's General Drawings.

If general drawings are submitted by a contractor as a part of his proposal, they shall include all stress sheets and such details as are necessary to express the general intent of the proposal. They shall show all general dimensions, such as length of spans from center to center of end bearings, clear width of roadway, width from center to center of trusses, depth from gauge line to gauge line of chords, etc. They shall indicate the assumed loads, live and dead, on which the computations are based, the sections and sectional areas of all truss and lateral members, the sizes of rivets, the thickness of gusset plates, the sizes and arrangement of floor beams and joists and their connections, and the character and quality of the materials proposed for use in various parts of the structure.

Shop Drawings.

Upon the acceptance of a proposal and the execution of the contract, all working drawings required by the engineer shall be furnished by the contractor free of cost. No work shall be commenced or materials ordered until the working drawings have been approved by the engineer in writing.

Classification.

Two classes of bridges will be considered under these specifications—those which carry suburban or interurban electric cars and those which carry highway traffic only. The former will be designated as class A and the latter as class B bridges.

Types of bridges.

It is recommended that the type of bridge employed be selected as follows:

For spans up to 30 feet—rolled beams;
For spans from 30 to 40 feet—plate girders or rolled beams;
For spans from 40 to 80 feet—riveted low trusses or plate girders;
For spans from 80 to 200 feet—riveted high trusses; and
For spans over 200 feet—pin-connected high trusses.

Materials.

All parts of the superstructure except the floor shall be of rolled steel.

Length of Span.

In computing the stresses the length of span for the trusses or girders shall be taken as the distance from center to center of the end bearings; and for the floor beams, from center to center of the trusses.

Width of Roadway.

For class A bridges the clear distance between the center line of the car track and the nearest truss shall be not less than 7 feet, and on one side the clear distance between the center line of the car track and the truss shall be at least 12 feet. The width from center to center of trusses shall in no case be less than one-eighteenth of the span.

Head Room.

The clear head room for a width of 6 feet on each side of the center line of the bridge shall be not less than 15 feet.

Depth Ratios.

The ratio of depth to span shall be not less than the following

For rolled beams	1/20
For plate girders	1/12
For trusses	1/10

LOADS.

Dead Loads.

The assumed dead load shall be not less than the total weight of the completed structure. The following unit weights shall be used in computing the dead loads:

Steel	pounds per cubic foot	490
Concrete	do	150
Brick	do	150
Macadam	do	130
Asphalt	do	135
Sand or earth	do	100
Stone	do	160
Timber:		
Creosoted	pounds per foot b. m.	5
Oak, untreated	do	4½
Pine, untreated	do	4

Live Loads.

Class A.—For the floor and its supports and for the trusses of spans less than 50 feet in length the live load shall be assumed as follows:

On each car track a concentrated load of 24 tons evenly divided between two axles, spaced 10 feet center to center with wheels spaced

5 feet center to center on axles, shall be assumed to occupy a width of 6 feet on each side of the center line; on the remaining floor surface, exclusive of sidewalks, a uniform load of 125 pounds per square foot and on sidewalks a uniform load of 100 pounds per square foot.

For the trusses of spans between 50 feet and 100 feet in length, a uniform load of 1,800 pounds per linear foot for each car track (assumed to occupy a width of 12 feet) and 100 pounds per square foot of remaining floor surface, including sidewalks, shall be assumed. For the trusses of spans greater than 100 feet in length, the live load per linear foot for each car track and per square foot of remaining floor surface may be reduced, respectively, 50 pounds and 2 pounds for each additional 10 feet of span, provided that in no case shall these loads be reduced below 1,200 pounds and 80 pounds, respectively.

All class A bridges shall be assumed as also subject to the loading specified for class B bridges.

Class B.—For the floor and its supports and for the trusses of spans less than 50 feet in length, the live load shall be assumed as follows:

On any part of the floor surface a concentrated load of 15 tons on two axles spaced 8 feet center to center, with wheels spaced 6 feet center to center on axles and two-thirds of the load on one axle, shall be assumed to occupy a space 16 feet in the direction of traffic by 12 feet at right angles to that direction. On the remaining floor surface, exclusive of sidewalks, a uniform load of 125 pounds per square foot, and on sidewalks a uniform load of 100 pounds per square foot, shall be assumed.

For the trusses of spans between 50 feet and 100 feet in length a uniformly distributed load of 100 pounds per square foot of floor surface shall be assumed. For the trusses of spans greater than 100 feet in length the uniform load per square foot may be reduced 2 pounds for each additional 10 feet of span, provided that in no case shall the assumed live load be less than 80 pounds per square foot of floor surface.

Distribution of Stresses Due to Concentrated Loads.

In considering the concentrated load under class A, each wheel load shall be assumed distributed over an area of floor surface 5 feet square. In considering the concentrated load under class B, each wheel load shall be assumed distributed as follows: For reinforced concrete floors, protected by a wearing surface, 3 feet in the direction of traffic by 5 feet at right angles to that direction; for wood floors at least 3 inches thick the distribution in the direction of traffic shall be neglected in designing the joists and the distribution at right angles to the direction of traffic shall be taken as 4 feet.

Wind Loads.

The top lateral bracing in deck bridges and the bottom lateral bracing in through bridges shall be designed to resist a lateral wind

load of 300 pounds per linear foot, and one-half of this shall be treated as a moving load.

The bottom lateral bracing in deck bridges and the top lateral bracing in through bridges shall be designed to resist a lateral wind load of 150 pounds per linear foot.

Temperature Stresses.

Provision shall be made for stresses due to a change in temperature of 150° F.

Longitudinal Forces.

For class A bridges provision shall be made for a longitudinal force equal to 20 per cent of the weight of the heaviest electric train which could reasonably be expected to come upon the bridge.

Impact.

The maximum live-load stress in each member shall be increased to provide for impact by an amount to be determined from the formula $I=\frac{100\ S}{L+300}$, where

I = impact or dynamic increment due to the effect of moving loads;
S = computed live-load stress; and
L = loaded length of bridge in feet which produces maximum live-load stress in the member under consideration.

Centrifugal Force.

When curved tracks occur on class A bridges, the centrifugal force produced by two cars coupled together moving at 50 miles an hour shall be considered as an additional live load in designing the lateral bracing.

PROPORTIONS AND UNIT STRESSES.

All members shall be so designed that the stresses coming upon them may be accurately computed, and shall be so proportioned that the sum of the maximum stresses produced by the loads herein specified shall not exceed the following amounts in pounds per square inch.

Tension.

Axial tension on net section—16,000.

Compression.

Axial compression on gross section—$16{,}000-70\frac{l}{r}$, where "l" is the length of the member in inches and "r" is the least radius of gyration of its cross section in inches.

For class A bridges no compression member shall have an unsupported length exceeding 100 times its least radius of gyration for main

members, or 120 times its least radius of gyration for laterals. For class B bridges no compression member shall have an unsupported length exceeding 120 times its least radius of gyration for main members, or 140 times its least radius of gyration for laterals.

Bending Stresses.

Bending stresses on extreme fibers of rolled floor beams, joists, and girders, 12,500; on extreme fibers of built-up girders, 16,000; and on extreme fibers of pins, 20,000.

Shearing.

Pins and shop-driven rivets	10,000
Field-driven rivets	7,500
Plate-girder webs (gross section)	9,000

Bearing.

Shop-driven rivets	20,000
Pins and field-driven rivets	15,000
Wall plates on concrete masonry (1 : 2½ : 5)	500
Wall plates on stone masonry (ashlar)	500
Wall plates on stone masonry (rubble)	400
Expansion rollers (per lineal inch)	500*d*

(*d* is the diameter of the roller in inches.)

Alternate Stresses.

Members subject to alternate tensile and compressive stresses shall be proportioned to resist each kind of stress, and each stress shall be considered as increased by an amount equal to eight-tenths of the smaller stress in determining the sectional area. The connections shall be proportioned for the arithmetical sum of the stresses.

Combined Stresses.

Members subject to a combination of direct and bending stresses shall be designed so that the greatest unit fiber stress shall not exceed the allowable unit stress for the member.

Counters.

Wherever the live and dead load stresses are opposite in character, only two-thirds of the dead-load stress shall be considered effective in counteracting the live-load stress.

For class A bridges counters shall be so provided and proportioned that an increase of 25 per cent in the specified live load would not increase the unit stress in any member more than 25 per cent.

Net Section at Rivets.

In proportioning tension members the diameter of the rivet holes shall be taken ⅛ inch larger than the nominal diameter of the rivets.

Proportioning Plate Girders.

The flanges of plate girders shall be assumed to take all the bending moment, and the web shall be assumed to take all the shear. The compression and tension flanges shall have the same gross section.

THE FLOOR SYSTEM.

Floor Beams.

All floor beams shall be rolled or riveted steel girders and shall be rigidly connected to the trusses or side girders. They shall, when practicable, be placed at right angles to the direction of traffic.

Joists.

All joists shall be rolled or riveted steel girders and shall be rigidly fastened to the floor beams. When wood floors are used, the joists shall be riveted to the webs of floor beams by means of connection angles. The spacing of joists center to center shall be not greater than 3 feet.

Wood Floors.

Wood floors shall be constructed of first-quality timber of the kind specified by the engineer in writing or indicated on his drawings. For oak floors the minimum thickness of plank used shall be $2\frac{1}{2}$ inches, and for pine the minimum thickness shall be 3 inches. In no case shall the thickness of the floor plank be less than one-twelfth of the distance, center to center, between joists. All plank shall be laid with the heart side down at right angles to the direction of traffic. Spaces of approximately $\frac{1}{4}$ inch shall be left between adjacent planks.

Wood floors shall be provided with a wheel guard on each side of the roadway. Wheel guards shall be constructed of timbers having a cross section of not less than 6 inches by 4 inches, spliced with 6-inch lap joints, and shall be securely bolted to the joists at intervals not to exceed 5 feet.

Concrete Floors.

Concrete floors shall be constructed true to the dimensions shown on the drawings and in accordance with the specifications hereinafter following under the heading "Concrete masonry."

Drainage.

Adequate provision shall be made for draining all parts of the floor, and the water drained off shall go clear of all metal work.

DETAILS OF DESIGN AND CONSTRUCTION.

Minimum Thickness of Metal.

The minimum thickness of metal used in any part of the structure, except that used for fillers and other minor parts, shall be $\frac{5}{16}$ inch. For class B bridges, however, this specification may be modified by the engineer in writing to permit the use of standard channels and I-beams having web thicknesses of less than $\frac{5}{16}$ inch, provided that the modification is made as a supplementary clause to these specifications before the contract is awarded or is indicated on the engineer's general drawings.

Camber.

Truss spans shall be given a camber by making the horizontal projection of the top chord longer than the bottom chord by $\frac{3}{16}$ inch for each 10 feet of span.

Connections.

All connections shall be designed to develop the full strength of the connecting members and shall be of the character indicated on the engineer's drawings or by the engineer in writing.

Angles subject to tensile stress shall be connected by both legs, otherwise only the section of the leg actually connected will be considered effective.

The neutral axes of connecting members shall meet in a point.

Rivets and Rivet Spacing.

DIAMETER.—Rivets shall be either $\frac{7}{8}$ inch, $\frac{3}{4}$ inch, or $\frac{5}{8}$ inch in diameter, except when used in minor parts.

PITCH.—The maximum pitch in the line of stress shall not exceed 6 inches or 16 times the thickness of the thinnest outside plate. The minimum pitch shall not be less than 3 inches for $\frac{7}{8}$-inch rivets, $2\frac{1}{2}$ inches for $\frac{3}{4}$-inch rivets, and 2 inches for $\frac{5}{8}$-inch rivets. For plate girders the rivet spacing in the vertical legs of the flange angles shall be determined from the formula, $p=\frac{rh}{s}$, where "p" is the pitch in inches, "r" the permissible stress in one rivet in pounds, "h" the distance between lines of rivets in inches, and "s" the maximum shear in pounds at the section under consideration. In no case, however, shall the pitch exceed 4 inches.

EDGE DISTANCE.—The minimum distances from center of rivet holes to the nearest edge shall be not less than $1\frac{1}{2}$ inches, $1\frac{1}{4}$ inches, and 1 inch for $\frac{7}{8}$-inch rivets, $\frac{3}{4}$-inch rivets, and $\frac{5}{8}$-inch rivets, respectively. The maximum distance from any edge to the center of rivet holes shall not exceed 8 times the thickness of the thinnest outside plate or 6 inches.

Rivets in Flanges.

Unless otherwise specified on the engineer's drawings or by the engineer in writing, $\frac{5}{8}$-inch rivets shall be used for all flanges less than $2\frac{1}{2}$ inches wide, $\frac{3}{4}$-inch rivets for flanges between $2\frac{1}{2}$ and $3\frac{1}{2}$ inches, and $\frac{7}{8}$-inch rivets for all flanges over $3\frac{1}{2}$ inches wide.

Pitch at Ends.

At the ends of built compression members the pitch of rivets in the line of stress shall not exceed 4 diameters for a distance equal to twice the maximum width of the member.

Grip of Rivets.

The grip of rivets shall, in general, be not greater than 4 diameters. When it is necessary to make the grip greater than 4 diameters, the allowable unit shearing strength shall be decreased 1 per cent for each $\frac{1}{16}$ inch of additional grip.

Pin Connections.

All pins shall be sufficiently long to furnish full bearing upon the turned body of the pin for all connecting parts. All pins shall be secured by chambered nuts and the screw ends shall be sufficiently long to admit of burring the threads after the nuts are set.

No pin shall have a diameter less than three-fourths the width of the widest eyebar attached to it.

The several members attaching to a pin shall be so placed as to produce as little bending movement as practicable upon the pin; and they shall be held in place by means of filling rings.

All pin holes shall be so bored that when the pin is in place it shall be perpendicular to the axial plane of the truss, and each connecting member shall bear uniformly upon the pin. The diameter of the hole shall not be more than $\frac{1}{32}$ inch greater than that of the pin.

Pin holes shall be sufficiently reinforced to distribute the stresses properly over the full cross section of the members. Where "pin plates" are used, they shall contain a sufficient number of rivets to transmit their proportion of the bearing pressure, and at least one plate on each side shall extend not less than 6 inches beyond the edge of the nearest batten plate.

Riveted tension members having pin connections shall have a cross sectional area through each pin hole 25 per cent in excess of the net sectional area of the members. The sectional area of the metal between the pin hole and the end of the member shall not be less than 75 per cent of the sectional area through the pin hole.

Batten Plates and Lattice Bars.

The open sides of compression members shall be stayed by batten plates at the ends and by diagonal lattice bars at intermediate points. Batten plates shall be used at intermediate points when, for any reason, the latticing is interrupted.

Batten plates shall have a thickness of not less than $\frac{1}{4}$ inch nor one forty-fifth the distance between the lines of rivets connecting them to the flanges. They shall have a width parallel to the axis of the member not less than the maximum width of the member.

Lattice bars shall have a thickness not less than $\frac{5}{16}$ inch nor less than one forty-fifth their unsupported length. They shall be inclined to the axis of the member at an angle not less than 60° for single latticing nor less than 45° for double latticing. Double latticing shall be riveted at the intersection points.

The width of lattice bars shall not be less than 2 inches nor less than one-sixth the width of the member of which they form a part.

Abutting Ends.

Abutting ends in compression members shall be planed true to the angle of the joint and shall be sufficiently spliced on four sides to hold the connecting parts accurately in place. All joints in tension members shall be fully spliced.

Where splice plates are separated from the parts which they connect by intervening plates or fillers, the number of rivets on each side of the joint shall be increased by $33\frac{1}{3}$ per cent of the number theoretically required for each intervening plate.

Eyebars.

The thickness of eyebars shall not be less than $\frac{5}{8}$ inch nor less than one-seventh the width of the bar. Heads of eyebars shall be formed by upsetting and forging, and never by welding. The heads shall be so proportioned as to develop the full strength of the bar.

Eyebars shall be perfectly straight at the time they are bored, and all bars which work together as one member shall be piled, clamped together, and bored in one operation.

The eyebars composing a member shall be so arranged that their surfaces are not in contact. The inclination of individual eyebars to the axis of the member which they compose shall not be greater than 1 inch in 16 feet.

Rods.

No rod shall be used which has a cross sectional area less than $\frac{3}{4}$ square inch.

All rods having screw ends shall be upset, previous to threading, so that the net sectional area at the root of the threads shall be greater by at least 17 per cent than the net sectional area of the rod.

Compression Members.

Compression members shall be so designed that any part or segment of a member will be proportionately as strong as the member taken as a whole.

No web shall have a thickness less than one-thirtieth the distance between the lines of rivets connecting it to the flanges, and no cover plate shall have a thickness less than one-fortieth the distance between rivet lines.

Flanges of built members which have no cover plates shall have a thickness not less than one-twelfth the width of the outstanding leg.

Lateral System.

All lateral and portal bracing shall be made of shapes capable of resisting both compression and tension, and shall have riveted connections to the chords.

Laterals shall be as nearly in the plane of the axes of the chords as practicable. When eccentricity is unavoidable, however, provision shall be made for the maximum bending stresses which would be produced in the connections with the member fully loaded.

Portals for through bridges shall be as deep as the specified head room and depth of truss will permit. They shall consist of top and bottom struts and stiff intermediate bracing. All portals shall be provided with curved knee or corner braces.

Intermediate top struts in through bridges shall have a depth not less than that of the top chord, and, if the engineer so requires, they shall be provided with curved knee or corner braces.

End struts shall be provided at the ends of all bottom chords.

Sway Bracing.

All deck bridges shall be provided at each panel point with sway bracing made of shapes capable of resisting both tension and compression. The sway bracing shall extend the full depth of the trusses, and at the end of the trusses ample provision shall be made for transferring all wind loads to the piers or abutments.

Hand Railing.

A substantial hand railing not less than 3½ feet high and of appropriate design shall be constructed on the outside of footwalks, or, when footwalks are omitted, at the outside of the roadway.

Expansion and Contraction.

Provision shall be made for all bridge structures to change in length owing to temperature changes at least $\frac{1}{8}$ inch for each 10 feet of span, and joints shall be provided at such points in the floor and pavement as may be indicated on the drawings furnished or approved by the engineer.

Expansion Bearings.

For all beam and girder bridges expansion bearings shall be designed for motion to take place by sliding. For all truss bridges the expansion bearings shall preferably be provided with rollers or rockers, though for spans less than 80 feet in length the engineer may, in his discretion, permit the use of sliding bearings. All rollers or rockers shall have a diameter of at least 3 inches. In all cases the bearings shall be so designed that motion can take place in a longitudinal direction only, and shall be so placed at the time the bridge is erected that the shoe or bolster will occupy a central position on the bearing at the atmospheric temperature specified by the engineer in writing.

Shoes or Bolsters.

Shoes or bolsters shall be so designed as to distribute the load over the entire bearing, and shall be securely stayed against lateral or upward motion by anchor bolts. Fixed bearings shall be rigidly anchored to the masonry.

Bedplates.

Bedplates shall be designed to distribute the load over an area sufficiently great to keep the pressure upon the masonry within the hereinbefore specified limits. All bed and bearing plates on masonry shall be set on sheet lead not less than $\frac{1}{4}$ inch thick and the same size as the plate.

WORKMANSHIP.

General.

All parts entering into the structure shall be constructed in accordance with approved drawings. The workmanship and finish shall equal the best practice in modern highway-bridge construction.

Due regard shall be given the appearance of the finished structure, and any part of the structure which, in the opinion of the engineer, does not present a neat and sightly appearance shall be repaired or replaced as he may direct. The edges of sheared steel plates in main members shall be carefully faced or planed to remove defects caused by shearing.

Forging and Annealing.

All forging must be done while the steel is at red heat, and all forged parts must be annealed by heating the steel to a uniform dark-red heat and permitting it to cool slowly. No welds will be allowed.

Rivet Holes and Rivets.

In punching rivet holes the diameter of the punch used shall not be more than $\frac{1}{16}$ inch greater than the diameter of the rivet. Material more than $\frac{3}{4}$ inch thick shall be subpunched and reamed or drilled from the solid.

Rivet holes shall be so punched as to match accurately when the parts are assembled. Poor matching of rivet holes will constitute a cause for rejection.

Rivets shall be driven by mechanical power wherever practicable. All rivets must have neatly capped full heads and grip the assembled parts firmly. Tightening loose rivets by recupping and calking will not be allowed. All loose, burned, or otherwise defective rivets shall be removed and replaced.

Riveted members shall have their contact surfaces painted, and shall be pinned up and firmly drawn together with bolts before riveting is commenced.

Pins and Rollers.

Pins and rollers shall be accurately turned to gauge and entirely free from flaws of any character.

MATERIALS.

STEEL.

Process of Manufacture.

The steel shall be made by the open-hearth process.

Chemical Composition.

The steel shall be uniform in character and shall conform to the following requirements as to chemical composition:

Elements considered.	Structural steel.	Rivet steel.	Steel castings.
Phosphorus, maximum per cent:			
Acid	0.06	0.04	0.08
Basic	.04	.04	.05
Sulphur, maximum per cent	.05	.04	.05

Ladle Analyses.

An analysis shall be made by the manufacturer from a ladle test ingot taken during the pouring of each melt, to determine the percentages of carbon, manganese, phosphorus, and sulphur, and a record of this analysis shall be furnished the engineer free of cost.

Check Analyses.

If required by the engineer, a check analysis shall be made from finished material representing each melt. The percentages of phosphorus and sulphur shown by the check analysis may exceed the percentages specified above by 25 per cent.

Physical Properties and Tests.

The tensile strength, elastic limit, and ductility shall be determined by testing samples cut from the finished material after rolling. The samples shall be not less than 12 inches long and shall have a uniform sectional area of not less than ½ square inch.

Structural Steel.

Structural steel shall have an ultimate strength of not less than 60,000 pounds, and not more than 70,000 pounds per square inch, an elastic limit of not less than one-half the ultimate strength, and a minimum elongation of 20 per cent in 8 inches. For eyebar material not over 20 per cent shall show a tensile strength of less than 62,000 pounds or more than 68,000 pounds per square inch. Steel for pins may have a minimum elongation of 15 per cent. All structural steel shall withstand bending cold without cracking through 180° around a pin the diameter of which is one and one-half times the thickness of the specimen. Full size material for eyebars shall withstand bending cold without cracking through 180° around a pin the diameter of which is equal to the thickness of the material.

Pins over 7 inches in diameter shall be forged. Blooms for pins shall have at least three times the sectional area of the finished pin.

Rivet Steel.

Rivet steel shall have an ultimate strength of not less than 48,000 pounds and not more than 58,000 pounds per square inch, an elastic limit of not less than one-half the ultimate strength, and an elongation of not less than 26 per cent in 8 inches.

Rivet rods shall withstand bending cold without cracking through 180° so that the parts on each side of the bend come into actual contact throughout their length. When nicked and bent around a bar of their own diameter, they shall break gradually and give a fine, uniform, silky fracture.

Steel Castings.

Steel castings shall be used for drawbridge wheels, track segments, and gearing. They shall be true to form and dimensions, uniform in character, free from injurious blowholes or other defects, and finished in workmanlike manner.

When specimens having a uniform sectional area of at least ½ square inch for at least 2 inches of their length are tested, they shall show an ultimate strength of not less than 67,000 pounds per square inch, an elastic limit of one-half the ultimate strength, and an elongation of not less than 10 per cent in 2 inches.

TIMBER.

All timber used for purposes other than constructing temporary forms and false work shall be of the kind specified in writing by the engineer and of the first quality of the kind specified. It shall be free from all defects which would impair its strength or durability.

OTHER MATERIALS.

All other materials shall be of the kind and quality specified on the drawings or in writing by the engineer, or, in case of concrete masonry, as hereinafter specified.

PAINTING.

Shop Painting.

Before leaving the shop all steelwork shall be thoroughly cleaned and given one complete coat of such paint as is specified in writing by the engineer. Machine-finished surfaces shall be coated with white lead and tallow before being shipped or placed in the open air.

Inaccessible Surfaces.

All surfaces which are not accessible for painting after erection or after being riveted together shall be given before erection or before being riveted two coats of pure red lead and boiled linseed oil mixed in the proportion of 18 pounds of lead to 1 gallon of oil.

Painting After Erection.

After erection all metal work shall be thoroughly cleaned of mud, grease, or other objectionable material and evenly painted with two coats of paint of the kind and colors specified by the engineer. Linseed oil shall be used as the vehicle in mixing the paint for each of these coats and the separate coats shall be of distinctly different shades of color.

All recesses which might retain water shall be filled with thick paint or some waterproof material before the final painting, and the first coat shall be allowed to become thoroughly dry before the second coat is applied.

No painting shall be done in wet or freezing weather.

CONCRETE MASONRY.

Plans and Drawings.

All concrete masonry shall be built to conform with the lines and dimensions shown on the plans and drawings furnished or approved by the engineer in charge and which are hereby made a part of these specifications. In cases of discrepancies between figured dimensions and scale the figured dimensions are to govern.

Concrete.

The concrete shall be of the character and mixed in the proportions indicated on the plans or as may be indicated in writing by the engineer in charge, or as hereinafter specified. All concrete shall be prepared and placed in strict accordance with the following specifications and plans and the instructions of the engineer under them.

Cement.

The cement shall be of some standard brand of Portland cement satisfactory to the engineer in charge. No cement shall be used which, when tested, fails to conform to the United States Government specifications for Portland cement as contained in Circular 33 of the Bureau of Standards. Cement shall be delivered in sacks of 94 pounds net weight, and each sack shall be considered as having a volume of 1 cubic foot. Cement which contains lumps or has been damaged in any way by exposure to the weather or by other cause shall be rejected.

Sand.

The sand shall consist of dry, clean, quartz grains and shall not contain more than 5 per cent of clay, loam, or other foreign materials. The grains shall be well graded and of such size that all will pass a $\frac{1}{4}$-inch mesh screen and not more than 20 per cent will pass a No. 50 sieve.

Coarse Aggregate.

The coarse aggregate may consist of either broken stone or gravel. Stone shall be sound, hard, and tough, broken to the sizes hereinafter specified, and when used shall be free from foreign material. No weathered or disintegrated material shall be used. Gravel shall be composed of hard, sound, durable particles of stone, thoroughly clean and well graded in size between the limits specified below.

Classes A, B, and C.

Unless otherwise especially provided, there shall be three classes of concrete, known as class A, class B, and class C.

Class A concrete shall consist (by volume) of 1 part of cement, 2 parts of sand, 4 parts of coarse aggregate, and water. All of the

coarse aggregate shall be retained on a $\frac{1}{4}$-inch mesh screen and shall pass a 1-inch mesh screen. Not more than 75 per cent shall be retained on a $\frac{1}{2}$-inch mesh screen, and not more than 75 per cent shall pass such a screen.

Class B concrete shall consist (by volume) of 1 part of cement, $2\frac{1}{2}$ parts of sand, 5 parts of coarse aggregate, and water. All of the coarse aggregate shall be retained on a $\frac{1}{4}$-inch mesh screen and shall pass a $1\frac{1}{2}$-inch mesh screen. Not more than 75 per cent shall be retained on a $\frac{3}{4}$-inch mesh screen, and not more than 75 per cent shall pass such a screen.

Class C concrete shall consist (by volume) of 1 part of cement, 3 parts of sand, 6 parts of coarse aggregate, and water. All of the coarse aggregate shall be retained on a $\frac{1}{4}$-inch mesh screen and shall pass a $2\frac{1}{2}$-inch mesh screen. Not more than 75 per cent shall be retained on a $1\frac{1}{4}$-inch mesh screen, and not more than 75 per cent shall pass such a screen.

Mixing.

The cement and sand shall first be thoroughly mixed dry, in the proportions specified, on a proper mixing platform. Sufficient clean water shall then be admixed to produce a pasty mortar. To the mortar thus prepared shall be added the proper proportion of coarse aggregate, previously drenched with water, and the whole shall be mixed until every particle of the coarse aggregate is thoroughly coated with the mortar. Instead of the above method a mechanical mixer satisfactory to the engineer may be employed.

Size of Batch.

Concrete shall be mixed in batches of such size that the entire batch may be placed in the forms by the force employed within 45 minutes from the time that the first water is applied. No concrete is to be prepared from mortar which has taken an initial set and would require retempering.

Placing.

All concrete shall be carefully deposited in place and never allowed to fall from a height greater than 5 feet. Concrete shall never be deposited in running water, nor in still water, except under the direction of an engineer skilled and experienced in that special work.

As fast as concrete is put into place it shall be thoroughly tamped in layers not more than 6 inches thick, and the portion next to the forms shall be troweled by using a spade, or by other means, to bring the mortar into thorough contact with the forms.

Concrete shall not be deposited when the temperature of any of the materials composing it is below 35° F.; and if during the progress of the work freezing temperature threatens or is predicted by the

United States Weather Bureau, proper precautions shall be taken to protect from freezing all concrete laid within the four preceding days.

Forms.

Forms shall be so constructed as to continue rigidly in place during and after depositing and tamping the concrete. If during the placing of the concrete the forms show signs of bulging or sagging at any point, that portion of the concrete causing the distortion shall be immediately removed and the forms properly supported before continuing the work. The amount of concrete to be removed shall be determined by the engineer, and the contractor shall receive no extra compensation on account of the extra work thus occasioned. Forms for exposed surfaces shall be constructed of dressed lumber.

All forms shall be left in place not less than 36 hours and all supporting forms not less than 10 days after the concrete has been deposited. These periods may be increased at the discretion of the engineer in charge.

It is understood that all prices for concrete masonry shall include furnishing all materials and properly constructing all necessary forms.

Joints.

When the work of laying concrete is to be interrupted for a period greater than one hour and there are no reinforcing rods projecting, provision for a joint shall be made in the following manner: Square timbers 8 by 8 inches, or some other suitable size approved by the engineer, shall be bedded in the concrete throughout the length of the course for one-half their thickness and allowed to remain until the concrete has taken its initial set. When the work of laying concrete is resumed, the timbers shall be removed and the surface thoroughly wet. No joints will be permitted in reinforced-concrete beams, and in floor slabs the joints shall be vertical and parallel to the main reinforcing bars.

Finish.

Forms covering surfaces of the concrete masonry which are to be exposed shall be removed immediately after the expiration of the period of time necessary for such forms to remain in place, as fixed by the engineer, and all crevices which may appear shall be filled with 1 : 2 cement mortar. These surfaces shall then be finished with 1 : 2 cement mortar and a wooden float, so as to present a smooth, neat appearance.

Reinforced Concrete.

All reinforced arches, beams, floors, parapets, guard rails, and all concrete masonry measuring less than 9 inches in thickness shall be

made of class A concrete, unless otherwise specified on the drawings or directed by the engineer in writing.

Abutments and Wing Walls.

Unless otherwise specified on the drawings or in writing by the engineer, class B concrete shall be used for all abutments and wing walls the thickness of which is not less than 9 inches.

Footings and Cut-off Walls.

Class C concrete shall be used for all footings and cut-off walls, unless otherwise specified on the plans or directed in writing by the engineer.

Steel for Reinforced Concrete.

Unless otherwise specified on the drawings, all reinforcing steel shall consist of bars which have been deformed in some approved manner. No plain bars will be permitted except as shown on the drawings or directed in writing by the engineer.

The steel bars shall have the net sectional area and shall be placed in the exact positions indicated on the drawings.

Unless otherwise specified on the drawings or in writing by the engineer, all reinforcing bars shall be of medium steel having an elastic limit of not less than 35,000 pounds per square inch, and shall be sufficiently malleable to withstand bending cold with a radius equal to twice the diameter or thickness of the bar through 180° without fracture.

When placed in the concrete, the reinforcing steel shall be free from grease, dirt, and rust, and it shall be the duty of the contractor to provide means for properly cleaning the steel.

Thorough contact of the concrete with every portion of the surface of the steel shall be obtained.

Splicing Reinforcing Bars.

Unless otherwise specified on the drawings or in writing by the engineer, necessary splices in reinforcing bars shall be effected by overlapping the ends of the bars a distance equal to 40 times their thickness or diameter.

INSPECTION AND TESTING.

Orders for Materials.

All materials used in connection with the work being done under these specifications shall be purchased especially for that work. The contractor shall furnish the engineer with complete copies of all orders for materials, and shall make all orders subject to the engineer's approval of the materials.

Acceptance of Material or Work.

The engineer or his representative shall stamp each accepted piece or parcel with a private mark, and any material not so stamped may be rejected at any stage of the work. The engineer's acceptance, however, does not relieve the contractor from responsibility for faulty material or workmanship and wherever such faulty material or workmanship is discovered it shall be repaired or removed and replaced, as the engineer may direct, by the contractor at his own expense.

Shop Inspection.

The contractor shall furnish the engineer or his representative all facilities for testing materials and workmanship at the shop where the material is fabricated, and shall notify the engineer well in advance of beginning the shop work.

Mill Inspection.

The contractor shall furnish all facilities for testing the weight and quality of all material at the mill where it is manufactured. He shall provide, free of cost, a suitable testing machine for making the tests and such test specimens as the engineer or his representative may require.

ERECTION.

Contractor's Responsibilities.

Unless otherwise specified in writing by the contracting parties, the contractor shall furnish all labor, tools, machinery, and materials for erecting the bridge complete in place and ready for traffic, in accordance with these specifications and the plans furnished or approved by the engineer.

The contractor shall do all necessary hauling, set all stone or anchor bolts, remove existing structures when necessary, and perform all other incidental work for which express provision has not been made.

The contractor shall so conduct all his operations as not to interfere with the work of other contractors or close any thoroughfare by land or water except by written consent of the engineer.

The contractor shall assume all risks of damage or accident to persons or property prior to the final acceptance of the finished structure.

The contractor shall remove all false work, piling, and other obstructions produced by his operations, and shall perform any additional work necessary to produce a sightly appearance in the immediate vicinity of the structure.

Final Test.

Before final acceptance the engineer may, at his discretion, make a thorough test of the structure by passing over it the specified loads or their equivalents, or by resting the maximum load upon the structure for 12 hours.

If any part of the structure fails to return to its original position after the load is removed, the contractor shall make such alterations as are necessary to enable the structure to stand the test without permanent change of any of its parts.

SUPPLEMENTARY.

The following supplementary clauses shall also apply to the work included in the contract of which these specifications form a part: